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GROUP MANAGEMENT OF WATER COMPANIES.

BY REEVES J. NEWSOM.*

[Read September 21, 1933.]

Group management of water companies can be successful and efficient only when the officials of the central organization are thoroughly experienced in operating problems as they arise in the field and when local managers, through proper treatment by the central office, are glad to coöperate in furnishing data and information which are accurate and complete and are willing to put into operation, with a spirit of enthusiasm, the decisions of the management company officials.

There are certain obvious advantages to the centralized management of a large group of water companies, and there are also, under certain conditions, disadvantages to such a plan. Among the advantages are these:

(*a*) There is made available to subsidiary companies, both small and large, a more expert type of direction and counsel in the many phases of the work than individual companies could afford;

(*b*) Because of the large number of problems constantly confronting the management company, the top-men in the organization are always gainfully employed, thereby reducing waste time and cost to the minimum;

(*c*) Subsidiary companies get the benefit of comparisons with, and the successful methods of, other companies which makes possible standards of operation beyond those humanly possible for any one official or group of officials on a single property;

(*d*) Mass purchasing of materials and equipment, insurance, legal service, auditing, etc., prevents duplication and reduces unit costs to a minimum;

(*e*) The operation, under the direction of single heads, of central and district billing and accounting offices, chemical laboratories, meter repair shops, etc., produces a uniformity of results at lowest possible cost;

(*f*) Standardized methods of design, construction and operation allow short cuts which greatly reduce engineering costs and speed up the work.

Among the drawbacks to group management are the following:

(*a*) There is the danger of over-development of the functions of the

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central office, leading to the compilation of needless data by individual plants and the employment of a large staff checking and filing data which are never, subsequently, used;

(*b*) Centralized control, if carried too far, may possibly cause the loss of self-respect and ambition in local plant managers by making them mere rubber stamps, and consumers may be irritated by the necessity for the local man to refer to the central office for authority to settle what should be routine problems;

(*c*) Serious results may arise if there is a lack of understanding of actual operating conditions by the officials in the central office.

It was the belief of the writer, in forming his organization, that the best and most economical results are obtained with a minimum force in the central office, a maximum of responsibility placed with the local managers and with the least possible exchange of forms, reports and correspondence that will enable the central office to intelligently guide the policies and operating practices of the individual companies.

The management company which operates the subsidiary companies of the Community Water Service system consists of the following organization under normal conditions:

(*a*) A President who acts as General Manager and Chief Engineer and who has general charge of the operations and the construction of new works, makes the decisions for all subsidiary companies regarding matters of policy, public relations, employment, rate controversies, litigation, relations with regulatory bodies, the necessity for new and additional works, the budgeting of expenditures for operation and construction, the type, size and design of engineering works and puts the final approval on the reports of subordinates dealing with these matters;

(*b*) An Executive Vice-President and Treasurer who has general charge, for all subsidiary companies, of all financial matters including the care of cash, the use of banks, the raising of funds, the investments and securities, cash and operating budget forecasts, financial reports to the public, taxes, insurance, auditing, accounting and collections;

(*c*) A Secretary who is an attorney and who keeps the minute books and records of all subsidiary companies, arranges all directors' and stockholders' meetings, supervises all contracts and furnishes the necessary legal advice on all but very special matters.

These three men are directors of all subsidiary companies and also serve, respectively, as President, Treasurer and Secretary of these companies thus largely eliminating the salaries and fees usually paid for such services in individually operated companies.

(*d*) A Comptroller who has charge of the accounting and billing in all operating and district offices as well as the keeping of the consolidated books of the holding company;

(*e*) An Assistant to the President who handles all general matters over which the President has direct supervision, particularly rate problems,

budgets, the purchase of materials and the control of operating and construction expenditures;

(*f*) A Mechanical Engineer who supervises the operation of all pumping station equipment, standpipes and electric transmission lines and does the necessary engineering in connection with the purchase of such equipment;

(*g*) A Civil Engineer who designs and supervises the award of contracts for dams, filter plants and water transmission lines with such drafting and other assistance as the volume of work requires;

(*h*) A Purification Engineer and Chief Chemist who is responsible for the quality of water delivered by all subsidiary companies and who directs the work of district laboratories through which the necessary control of all purification, softening and other treatment is exercised;

(*i*) A water-meter expert who trains all meter-repair men, supervises the work in all testing plants, the installation and replacement of all meters and the testing of large meters in place;

(*j*) An expert in wastage detection and difficult maintenance and construction who directs pitometer surveys, the repair of leaky dams and reservoirs and the construction and repair of river and other under-water crossings;

(*k*) An accountant who is an expert on taxes and insurance and who supervises the tax returns to all state tax bodies and the consolidated Federal tax returns for all subsidiary companies and the holding company;

(*l*) A staff of senior and junior accountants, chemists, draftsmen, stenographers and clerks, totaling about fifteen.

This central organization of twenty-five, together with three district managers and two district superintendents, operates forty-six water works plants in eleven states, serving communities varying in population from 3 000 to 125 000 and having locally, as chief official, a manager, a superintendent, or a foreman, depending upon the size of the plant. There are four district purification laboratories and four central meter-repair shops. The accounting and billing is done locally in six plants and that for the other forty in four district offices.

Consumers accounts are handled by the so-called bookless bookkeeping method. Machine billing is in general use and the bills are made directly from the meter-reader's books. These meter readings are not transferred to a ledger, but the bills are made in three parts, one of which becomes the office record of the account. This is filed as an account receivable and is removed to a permanent record file when the account is closed.

For the purchasing of all materials and equipment, no purchasing agent is required. The contracts for about a dozen of the principal items of materials and equipment are arranged under the direction of the Assistant to the President and, thereafter, all purchases for the subsidiary companies are made directly by the local managers, and all invoices are paid by the respective accounting offices in the field upon approval by the managers.

The control of all expenditures is exercised in simple fashion by the central office. Budgets covering the various classes of work to be done are set in December for the following year after a canvass of each manager's estimate of requirements. Such budgets are not, however, authority to make expenditures but, in all cases involving an outlay of $200 for large plants and $100 for small plants, an individual expenditure authorization form is forwarded to the central office for approval as to inclusion in budgets, correctness of size, type and design, and proper consideration of the future needs of the system. Such requests pass through the hands of the district manager involved and must first have his approval.

The revenues collected by each company are deposited locally in treasury accounts, and all bills are paid from manager's accounts, also carried in local banks. The transfer of funds from treasury to manager's accounts calls for the forwarding to the central office of a reimbursement request which gives in detail the amounts paid, the purpose of the expenditure and the company to whom it was made. This keeps the central office informed as to how funds are expended, whether purchases have been made from purveyors who are under contract, whether the limits requiring specific authorization have been observed, and what is the amount of money that is being spent below such limits. Such check-up comes after the money is spent, to be sure, but it involves much less red tape than does centralized purchasing of all items, and for all practical purposes it is sufficient. To see that all unit prices are correct for major purchases, triplicate invoices from all concerns holding contracts are forwarded to the central office. These are checked against both expenditure authorizations and reimbursement requests. Upon the completion of any project for which an expenditure authorization has been issued, a similar form is filed with the central office showing the actual cost which is checked against the original estimate. Thus, the ability of local managers to correctly estimate costs is under constant scrutiny. This procedure, while principally used for plant improvements and major replacements, serves equally well to control routine expenditures for maintenance and operation other than company labor.

Revenues and costs of operation and maintenance as well as general expense and taxes are also budgeted and simply controlled. In addition to the monthly financial reports from the accounting officers, which give the figures, a monthly commentary is required from each manager which gives the reasons for any variation, either up or down, in items of revenue and various classifications of expense from that for the same month the year before and which includes a comparison with the budgeted amounts for each item.

At the beginning of each year, operating budgets are prepared in the central office and are spread on large sheets which break down the amounts by classes of work and by months on the basis of past experience in each plant. One such sheet goes to each manager and a duplicate remains in

the central office. Each manager is then required to keep his own comparison of actual and budgeted expenses so that he will at once see the variation and include the explanation in his monthly letter before it is asked for. This prevents his results from getting very far out of line without his notice and enables him to take steps to get back within his budget before it is too late.

Managers also furnish a brief report monthly on the results of the operation of pumping equipment. These results are tabulated in the central office and the trends watched for loss of efficiency or excessive costs of labor, fuel or maintenance. This monthly operating report also contains the results of purification or softening and indicates success or failure in maintaining proper quality standards and any excessive use of chemicals to produce the required results. Purification results are more closely checked by the constant tests of samples in the district laboratories. Any variation not immediately corrected is reported to the central office for the attention of the purification engineer.

Meter repairs, under the direction of a central office man who travels constantly between the various repair shops and the plants, are carried on by factory methods in dismantling, repairing, assembling and testing, and the requirements are higher than is customary. New meters also must come within limits considerably closer than those set in the Water Works Association standard specifications. Specialization in meter work by men highly trained and the shipping of meters to district shops has been found to be extremely profitable.

The form of monthly financial reports, the methods of forecasting the flow of cash and the plans to provide the same when needed are extremely important. A forecast of cash movements six months in advance is made and revised each month on the basis of reports and estimates from each manager on the fifth of the month.

Voluminous financial reports are costly to prepare and they are, therefore, minimized. However, sufficient data must be included to enable the central office to watch the trends. A safe minimum of information includes for each subsidiary, monthly, a balance sheet, a condensed income statement, a breakdown of revenues and expenses into major classes with a comparison for the month, for the accumulated months, and for twelve months ending with similar periods the year before, a detailed comparison at least quarterly of the subdivisions of operating and maintenance expenses, a monthly comparison of the changes of the different classes of fixed capital, an analysis of the receipts and disbursements of cash with a forecast of the same two months in advance, and an analysis of the changes in surplus. Such reports are due in the central office the fifteenth of each month, and the consolidated balance sheet and income statement with monthly, accumulated and yearly comparisons for the group, as a whole, is completed on the twenty-fifth.

By the time the last meeting for each month of the Board of Directors

of the holding company is held, the results of the previous month's operation and construction are at hand, comparisons with budgets have been made, explanation of changes by managers have been received, cash forecasts have been revised, and the officers of the management company are prepared to report on their stewardship and to recommend such action as is necessary by the Board to meet any change in conditions.

For discussion of this paper, see p. 351.

MANAGEMENT OF A MUNICIPALLY OWNED WATER WORKS.

BY LELAND G. CARLTON.*

[*Read September 21, 1933.*]

The general principles underlying the management and operation of a water works plant, whether it be large or small, privately or municipally owned, are the same in every case. The water is collected either from streams, wells, or lakes; delivered under pressure, by pumps or gravity, through a distribution system, and service pipes to the consumers. There it is sold by meter or flat rate, the bills rendered, collections made, if possible, and the returns used to defray the expenses of the works. The difference in management hinges on the detailed principles of operation.

The purpose of preparing this paper is to bring before this Association the plan of organization, duties of the personnel, and some of the methods of operation of a municipally owned water department, so that these plans, duties, and methods may be compared or contrasted with those of a large operating company having several plants under its management and possibly plants with which the readers are familiar.

The municipal plant to be used as an example, is the Municipal Water Works of the City of Springfield, Massachusetts.

In order that the reader may have a mental picture of the size of this plant, a few of its statistics are given as follows:

Valuation (Not taking into account depreciation)	$16 000 000
Annual revenue	$980 000
Gravity supply with storage capacity	26 billion gallons
Range of pressure	80 to 140 lb. per sq. in.
Size of distribution system	320 miles
Pipe sizes	1 to 54 in.
Number of gate valves	9 000
Number of hydrants	3 000
Number of retail private consumers	23 000
Number of wholesale municipal consumers	6
Average annual consumption	14 m.g.d.

Organization. The organization consists of a Board of Water Commissioners, Engineering Division, Superintendent's Division, and Financial or Commercial Division, with all collections being made by the City Collector, all invoices and pay-rolls of the department being paid by the City Treasurer, and all accounting being verified by the City Auditor. The last three agencies are mentioned merely to show that they are the only connections between the department and the other governmental departments of the city.

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The Springfield Water Department functions as a private utility, paying all charges of bond principal and interest and all costs of construction and operation solely from its own revenue. The department receives no income from hydrant rentals or from water furnished for any other city use; it does, however, have to pay for all pavement repair work.

Duties. The duties of the Board of Water Commissioners are to determine the executive and administrative policies of the department.

The Engineering Division has charge of the construction, operation and maintenance of all structures pertaining to the source of supply. These are located outside of the city, and include dams, storage reservoirs, filtration works, and supply mains. This division also performs any engineering work which is required by the Superintendent's Division.

The Superintendent's Division has charge of all construction and maintenance work within the city, including the laying and maintaining of all water mains, the repairing of leaks, the inspecting of hydrants and gate valves, the installing and maintaining of services, the setting, testing, and repairing of meters.

The Financial Division has charge of the reading of meters, the figuring and preparing of quarterly water bills, of pay-rolls, and of all accounting work of the department. It prepares monthly statements for the Board, showing the cash receipts and expenditures, the status of the budget, the balance sheet, also the construction, operation and maintenance costs.

Personnel. The Board of Water Commissioners is composed of three members, two of whom are elected by the City Council, alternately, for a term of two years. The third member is the Mayor of the City. The positions are entirely honorary. Usually, men who have made a success of business in private life are elected to the Board, probably with a thought that the city will benefit from their experience.

The Engineering Division is in charge of the Chief Engineer of the department. The personnel of this division includes the Chief Engineer, Assistant Chief Engineer, three draftsmen and clerks, and a superintendent and chemist who, together with the necessary foremen, mechanics and laborers operate the filtration plant. At each storage reservoir a caretaker and a varying number of laborers, depending upon the season, perform the necessary work around the reservoir. During periods of construction, the engineering force is augmented by the addition of resident engineers and the required number of men necessary for the surveying and inspection of the new work.

The Superintendent's Division is headed by the Superintendent of the department, as the name implies. The personnel of this division has been somewhat reduced during the past two years; at present it consists of a Superintendent, a storekeeper and two clerks for office work, a foreman, chauffeur, pipe men and sufficient laborers for any main-pipe-laying work that has been authorized.

A foreman and four laborers form each service gang; additional service

gangs are made up at times when this class of work so requires. A foreman and three laborers are always kept busy repairing small leaks and taking out and resetting large meters which have been ordered to the shop for testing. A foreman and four laborers install fire services, make small main-pipe extensions, repair leaks and perform the miscellaneous hydrant repair work. A foreman and two laborers operate every gate valve in the system at least once a year, making the necessary repairs to these valves, relocate stop boxes and inspect hydrants during the winter. A garage foreman and two helpers make all necessary repairs to the trucks and passenger cars. During the winter each truck is thoroughly overhauled, and usually painted. These same men act as an emergency crew during the day time. A foreman and three men form the night-emergency crew. When not out on emergency calls, their time is occupied by cleaning and wiping off the cars, filling the gas tanks, and cleaning the building. A meter foreman has charge of the machine shop and has under him a clerk, a mechanic, two meter-repair men and two meter gangs made up of a driver and helper to bring in and reset meters, also to clean out any service pipes which have been so ordered.

All of these men in the Superintendent's Division report and work from a service building which is located near the geographical center of the city, on a railroad siding, where the city maintains its pipe-storage yard.

The Financial Division is in charge of the Registrar, who is also Clerk of the Board. Serving under the Registrar, are an accountant, bookkeeper, journal clerk, and two pay-roll clerks, who also summarize the returns made out by the foremen, getting the costs ready for the journal clerk, a chief clerk and assistant, who handle all of the business in the public office. As has been previously stated, the reading of the meters, and the making out of the bills comes under this division. To perform this work, there are eight meter inspectors, a chief inspector, and seven others, also four billing clerks. Three other clerks keep the office records up to date, that is, the changes of ownership, off and on records, sales bills, etc. There is also a registrar's secretary, and a department messenger.

Methods of Operation.

Budget. At the beginning of each fiscal year, it is necessary to prepare a budget of the current expenses of the department. The items set up in this budget are Personal Services, Services other than Personal, Fixed Charges, Supplies, Materials, Equipment and Parts, Miscellaneous, Reserved and Total.

These items may be explained as follows:

Personal Services includes salaries and wages of permanent and temporary employees and fees for personal services not elsewhere provided for.

Services other than Personal includes costs of transportation of persons and materials, communication service, printing, binding, advertising, and furnishing light and power.

Fixed Charges includes cost of rent, insurance, taxes, pensions and, last but not least, bond payments and interest.

Supplies includes costs of office, drafting room, engineer's medical and laboratory supplies, fuel and provisions.

Materials includes costs of raw materials, metal products, lumber, paint, etc.

Equipment and Parts includes costs of heat, power, construction and conveying equipment, furniture and all other equipment.

Miscellaneous includes costs of all other items not classified.

Reserved is the give and take account; it includes the balance of the funds not assigned to any other item.

As has been previously mentioned, the department is entirely self-supporting, consequently the Total of the Budget must not exceed the anticipated revenue for the current year. Besides the revenue received for water, the department receives $270 000 a year from a thirty-year lease of a hydro-electric station which it owns and leases to a power and light company.

The budget is sub-divided into three division budgets, each covering the same main items as the original and representing the funds allotted to each of the three divisions of the department. Once a month, the expenditures of the three divisions are subtracted from the amounts set up under the various items and the status of the budget presented to the Board.

Water Bills and Collections. As long as the department cannot function without funds and these funds must be obtained from the sale of water and the power lease, perhaps the next most important duty that should be outlined is that of making out the water bills and getting the receipts into the funds of the department.

There are 23 000 private consumers in the city, and as these are billed quarterly it would be impossible to perform all of this work at the first of every third month. Consequently, the city is divided into three sections, one section being billed monthly. To outline this work, we shall consider what we term Section A. This section of the city is divided into forty-seven subdivisions, and one meter book covers each of these subdivisions. The limits of these subdivisions are fixed so that they will contain about 150 meters. In the front of each meter book is a fly leaf, called a "route sheet," which contains the order of reading the meters, listed by the owner's names. The remainder of the book contains a sheet for each meter in this subdivision on which is listed the name of the owner, street and number of the property, the size, kind, and number of the meter, and its location on the property. These sheets are arranged alphabetically in the books according to the owners' names. This combination enables the meter inspector to cover these subdivisions systematically with very few instances of return trips through the same street.

The inspectors are able to read on an average, about 130 meters a day. As a book is completed, it is returned to the office and taken up by one of the billing clerks who computes the bills for all the meters listed in that

book. Another clerk draws off the bills, at the same time checking the figuring of the first clerk. These bills have previously been addressed and arranged in the same alphabetical order as are the meter sheets in the book.

After all of the books in a section have been read and the corresponding bills made out, all of these bills are combined alphabetically, so that they may be drawn off on the commitment sheets. The originals of these commitment sheets are forwarded to the City Collector for his records, their duplicates being retained in the Water Department; the bills are mailed to the owners, or agents of the properties.

If a bill remains unpaid, the owner receives a second notice after twenty days, and a final notice after thirty days; shortly after that, the service is shut off for non-payment of the bill, and the water is not turned on until the bill and an additional charge of two dollars have been paid. Bills that are not paid at the end of sixty days are subject to a lien being placed upon the property.

Once a week, the City Collector turns over to the City Treasurer all money received during that week, thereby transferring this money into the city department that pays all invoices and pay-rolls, as mentioned earlier in this paper.

Installing Service Pipes. The next operation that should be described is that of installing a service pipe. The owner comes to the public office and signs an application, which is called a Service Return, giving the street, number and size of the house to be supplied and the size and kind of pipe desired. He is required in every case to make an advance deposit, which is supposed to be large enough to pay the entire cost of installing this service. The clerk who takes this application makes out the meter order for the job, which gives the size and kind of meter to be set, also a meter sheet to be placed in the meter book covering the subdivision in which the property is located. The service return and meter order are forwarded to the Superintendent's Division, where a tapping order is made out. This order gives the same information as is on the service return, also the location of the main, size of tap to be made and any other information which the service foreman may require.

The service gang does the work, and the foreman makes out a foreman's return, covering the hours of labor, material used and also the location of the stop box, and he returns these papers together with the meter order, with the number and make of meter and its reading, to the Superintendent's office.

A clerk then makes out a service card, which is kept on file in the Superintendent's office. This card carries the name of the owner, address of the property, date of the service installation and location of the stop box and corporation. On the back of the card is made a sketch, not to scale, of the street, house, location of the main and service pipe. The location of the stop box is also typed on the original service return, and

this, with the foreman's return, is sent to the Financial Division, where the cost of the work is figured and entered in the journal and a sales bill made out. This sales charge is also entered on the commitment which goes to the City Collector. If the advance deposit made by the owner at the time he signed the Service Return is larger than the cost of installing the service, he is mailed a check for the difference and his receipted sales bill. On the other hand, if his deposit is less than the cost, he is notified of this fact and requested to come to the office and pay the difference.

Extension of Mains. An order for laying cast-iron pipe is brought about by two different means, either by direct order of the Board, complying with a request of the Superintendent, or by the approval of a guarantee-revenue petition. This term refers to the system used in Springfield, whereby an individual, or group of individuals, makes application for the extension of a main pipe in a street, on which he or they may own property. The department requires that an annual revenue of twenty dollars per hundred feet of main be guaranteed for this work and that the signers place opposite their names the amount they so guarantee, with the understanding that any revenue received for water taken from the main shall be credited to the signers, and that whenever the revenue received for water equals the guaranteed amount, the guarantee-revenue petition is cancelled. The department reserves the right to lay the size of main which it deems best suited to the street.

When the request for laying the main has been approved by the Board, a street order is issued to the Superintendent to do the work. This order states the name of the street, size and length of main to be laid and date of approval. The order is next given to the main-pipe foreman who makes out a requisition slip for all material that is to be used on the job. The main-pipe gang completes the work, and the foreman makes out his foreman's return. This return covers the hours of labor, amount of pipe laid and any other material used, location of the pipes, hydrants, gate valves and blow-offs and contains any other information which will be of assistance in years to come. The foreman is also required to list any gate valves which he has operated during this work, stating the condition in which he found them and in which he left them. A sketch is also made of the work, showing the location of all fittings and specials that have been used. This also gives the date, name of the street, name of the foreman and the kind of pipe and jointing material used. This information is forwarded to the draftsmen who keep the distribution system plan up to date and is later placed on file in the Superintendent's office.

The foreman's return is handed to the storekeeper who checks the material used with the amount listed on the requisition slip for the job; then it is returned to the Financial Division where the unit costs are figured, the expenses entered in the journal and ledger, the cost of the material deducted from the inventory account, the cost of the work added to the

plant account and the job set up in the plant ledger to be depreciated year by year.

Card System. When describing the details connected with the installing of a service pipe, mention was made of a service card. These cards are about 4 by 5½ in. in size and contain all the information pertaining to the service, together with a sketch of the work on the back of the card. They are the only records of the services that are kept in the Superintendent's office, and as most of the telephone trouble-calls are received in this office, the cards form a very important part of his records. They are filed in steel cabinets in order of the house number under the name of the street, and are easily found when wanted.

Another card system that is maintained in the Superintendent's office is one pertaining to the gate-valves in the distribution system. There is a card for every gate valve, carrying the size and make of valve, the year it was made, the year it was installed, the place it was installed and its locations, also the number of half turns to operate it. The rest of the card, front and back, is ruled so that entries may be made on it of what foreman operated the valve, when and why, the condition in which he found it, *i. e.*, opened or closed, or half opened, etc., and the condition in which he left it. As every valve is operated once each year for inspection, these records give a very good check on the condition of the valves. Further, each gate valve has been given a number for identification. This number appears on the card, and it is by this number that they are filed; the number also appears on the distribution-system plans and in the gate record books.

Operating Expenses. Those who have direct contact with the management of a water works realize that not only must the collections be carefully watched, but also the expenditures. Perhaps the items carried under Operating Expenses may, therefore, be of interest.

The main items of the Income and Profit-and-Loss Account are Source of Supply Expense; Transmission Expense; Engineering Expense; Distribution Expense; Commercial Expense; Stores Expense; General Expense; Other Expense; Utility Expense; Depreciation Reserve Charge. Most of these have been further subdivided so as to keep well separated the details which make up these main items. The following is a schedule of some of these subdivisions.

Source of Supply Expense
- Operating Labor
- Supplies and Expenses
- Sanitation Labor
- Sanitation Expense
- Forestation Labor
- Maintenance of Buildings, Fixtures and Grounds
- Maintenance of Structures and Equipment
- Purification Labor
- Purification Supplies and Expenses
- Purification Maintenance of Buildings Fixtures and Grounds
- Purification Maintenance of Structures and Equipment
- Structures and Equipment

Transmission Expense
- Maintenance of Ludlow Main No. 1
- Maintenance of Ludlow Main No. 2
- Maintenance of Little River Main No. 1 (42-in.)
- Maintenance of Little River Main No. 2 (48-in.)
- Connecticut River Crossing Nos. 1 and 2
- Little River Telephone System

Engineering Expense
- Salaries of Engineers and Draftsmen
- Salaries of Officers and Clerks
- Office Expense
- Miscellaneous Engineering Expenses

Distribution Expense
- Maintenance of Mains
- Maintenance of Gates and Valves
- Street Department Work — Miscellaneous Expense
- Meters and Fittings — Operating Labor
- Meters and Fittings — Supplies and Expenses
- Maintenance of Meters
- Maintenance of Hydrant Meters
- Installing Meters
- Maintenance of Services
- Cutting off Discontinued Services
- Cleaning Services
- Shutting off and Turning on Services
- Bills Charged to Consumer
- Hydrants — Fire Alarm Calls
- Hydrants — Maintenance
- Fountains and Troughs — Maintenance
- Consumers Premises Expense
- Maintenance of Service Building — Colton Street
- Maintenance of Foremen's Houses
- Maintenance of Buildings, Fixtures and Grounds
- Maintenance of Equipment
- Salaries of Superintendents and Meter Foreman
- Salaries of Office Clerks
- Office Expense — Superintendent's Division
- Books and Publications
- Miscellaneous Expense

Commercial Expense
- Salaries
- Supplies and Expenses
- Maintenance of Commercial Office Equipment
- Reading Meters — Salaries
- Reading Meters — Supplies and Expenses
- Suburban Meters — Supplies and Expenses

Stores Expense
- Salaries
- Supplies and Expenses
- Maintenance of Buildings, Fixtures and Grounds
- Maintenance of Equipment
- Inventory Adjustments

General Expense
- Salaries — Registrar's Office
- Printing and Stationery
- Maintenance of General Office Equipment
- Miscellaneous Office Expenses
- Office Rent
- Books and Publications

Other Expense
- Pensions
- Injuries and Damages

Utility Equipment Expense
- Trenching Machine — Supplies and Expenses
- Trailer — Supplies and Expenses
- Air Compressor — Supplies and Expenses
- Automobiles — Supplies and Expenses

Depreciation Reserve Charge
- Buildings
- Structures
- Equipment
- Transmission mains
- Hydrants
- Services
- Meters
- Gate Valves
- Distribution Mains

At the annual convention of this Association held in September, 1916, at Portland, Me., the President appointed a committee to study the subject of "Water Works Accounting." The committee was as follows: Albert L. Sawyer, Chairman, Walter P. Schwabe, Samuel H. MacKenzie, Edwin L. Pride and Alfred R. Hathaway. This committee rendered its first report in Holyoke, Mass., in 1920 under the title "Classification of Uniform Accounting for Municipal Water Works," and the report was adopted by the Association at Bridgeport, Conn., in September, 1921. Mr. Hathaway was then Registrar of the Municipal Water Works in Springfield, Mass., and was the member of the committee who compiled the report. The accounting system adopted by the Association was that used in Springfield at that time; consequently it does not seem that its details should be repeated in this paper. Those who are interested in this accounting system are referred to the March issue of this JOURNAL, Vol. 25, 1921.

DISCUSSION.*

FRANK J. GIFFORD.† I would like to ask Mr. Carlton how he arrives at the cost of $20 per 100 ft. of main pipe.

MR. CARLTON. That was based on 10 per cent. of the cost of laying a 6-in. pipe. However, since prices vary, we adopted a fixed sum of $20 per 100 ft.

DAVID A. HEFFERNAN.‡ I would like to ask if you determine the loss of revenue incurred by supplying without charge the municipal buildings in the city of Springfield.

MR. CARLTON. Last year the revenue we would have obtained from all city uses, including hydrant rental, water used in the schoolhouses and all municipal buildings would have amounted to practically $90 000.

THEODORE L. BRISTOL.§ I would like to ask Mr. Carlton if he has to pay an income tax on his salary.

MR. CARLTON. Yes; Federal income tax.

MR. BRISTOL. That means that the municipality is in business.

MR. CARLTON. That is the ruling of the Federal Government.

MR. BRISTOL. If that is the case, why should not the municipal corporation itself pay taxes to the Government?

MR. CARLTON. Only a short time ago I received a circular from California in which that question was brought up, suggesting that waterworks officials should get together and stop such a development.

MR. BRISTOL. A private corporation has to pay taxes on its profits. Why should not a municipality pay also.

*Joint discussion of papers by R. J. Newsom, p. 337 of this JOURNAL, and L. G. Carlton, p. 343 of this JOURNAL.

†Community Water Service Co., Dedham, Mass.

‡Superintendent, Milton, Mass. §Ansonia Water Co., Ansonia, Conn.

PRESIDENT ELLIS.* I do not know that I can offer anything in addition to Mr. Carlton's answer to Mr. Bristol's question, but we must remember that at least in theory the municipal department is working not for profit but is returning to its consumers by way of reduced water rates, any surplus it may accumulate. That may have some bearing on the matter of Federal taxation.

MR. BRISTOL. The thought that has always gone through my mind is the discrimination between communities due to the fact that in one community, where water is supplied through a municipal corporation, the consumers are not paying the same tax as in another community where water is supplied by a private company.

PRESIDENT ELLIS. That is very true, but why pay a tax if you do not make money?

MR. BRISTOL. You ought to make money.

PRESIDENT ELLIS. What are you going to do with the money? In a municipal corporation each individual owner in the municipality is a part owner of the system, and you can return to him, as shareholder, his share of the profits only by way of a reduced rate. This, over a period of time, results in a municipal department receiving only sufficient revenue to cover gross operating expenses.

MR. BRISTOL. The point is: As far as the Government is concerned, any community that is served by a municipal corporation is not bearing its share of the Federal, State, or County taxes, because there is no tax on water.

PRESIDENT ELLIS. That may be an argument for municipal ownership. There is a wide difference between municipal and corporate ownership. I have heard of water companies advertising their products and wonder if a municipal department has been known to advertise its product. May I ask Mr. Newsom if the Community Water Service Company in any way advertises its product?

MR. NEWSOM. We get quite a lot of free advertising in the water business, but it is not always helpful to the company. We have experimented on trying to sell more water by advertising, and I regret to say that it has not been very successful. It is hard to tell people that they do not take baths enough, and there are not many uses to which water can be put that it has not already been used for. Some efforts have been made to increase the facilities in individual houses in the way of additional shower baths and lawn sprinkling equipment, and some companies have gone so far as to try to work out a coöperative plan with the plumbers in the city so that payment can be made over a period of time. Such efforts have been abandoned in our case because they have not been productive enough to justify them.

CARLTON E. DAVIS.† I would like to ask Mr. Newsom if he has noticed a change in local demands for improvement of water services when

*Water Commissioner, Newton, Mass. †Philadelphia Suburban Water Co., Bryn Mawr, Pa.

there has been a change from strictly local ownership to so-called foreign ownership?

MR. NEWSOM. There is a marked increase in the demand for improvements. In the average case the local ownership of a water company is usually vested in men of affairs in the community who oftentimes are liberal in their contributions towards undertakings of general civic benefit. As a result people appear to be willing to put up with some deficiencies in the quality of service, such as pressure and fire protection. Nearly always when such ownership changes from purely local to foreign hands the accumulated grievances of many years land promptly on the shoulders of the new owners. It was our experience in putting together a group of water companies that one of the things we had to be prepared to do was to spend a considerable amount of money for what might be called deferred maintenance as soon as the property had been acquired. If one did not figure on such an expenditure in the acquisition of a property one would soon find that one's investment was not working out as expected.

HUGH MCLEAN.* I wonder how it is that the Springfield Water Works pays $3 000 a year for rent of offices in the City Hall but makes no charge for the water used by the City.

MR. CARLTON. When the City Hall was built there was some opposition to the water department occupying some of its offices. The city government ruled that the department would have to pay rent. Since we pay no taxes to the city, this may be one reason why we do not receive revenue from the city for water that we supply. The water department is the only one that does pay rent.

MR. MCLEAN. Would it not be a great deal better to have the water department pay a tax, just as a private individual, and have the City of Springfield pay hydrant rentals and for the water it uses in public buildings, just as if it was a private company. I think that would be better bookkeeping. The city of Holyoke has adopted this plan. The water department pays a rent for offices in the City Hall amounting to $1 500 a year, and a tax of 10 per cent. on its net receipts from the sale of water, amounting to about $20 000 a year.

PRESIDENT ELLIS. I do not want to speak for Mr. Carlton, but I do not think Mr. Carlton is advocating the Springfield organization as a model to be followed. He has merely explained the operation of his own department.

HENRY T. GIDLEY. I would like to ask Mr. Carlton how much he estimates the city should pay per hydrant on the high service.

MR. CARLTON. The figure set up by ordinance is $25 per year. The ordinance requires that we keep in our accounts figures pertaining to the cost of water used by every city department and all hydrant rentals; that the department carry them on one side of its books and wipe them off on the other side. The ordinance also states definitely that the city shall not

*Holyoke, Mass.

pay for water used by city departments. I agree with Mr. McLean, and my predecessor Mr. Hathaway advocated for a long time that the city should pay for the water and the service it receives and that the department, on the other hand, should pay taxes on its property.

MR. NEWSOM. I would like to ask Mr. Carlton whether or not the mere keeping of the books serves a useful purpose in actually curtailing waste of water in public buildings and schools; and if not, if there is any other method of keeping that at a minimum?

MR. CARLTON. No, it does not in any way allow us to curtail waste. There is a meter in every schoolhouse, and if the inspector finds that a fixture is leaking or running he usually takes the matter up with the janitor; if nothing is done about it he takes it up with the Department of Public Buildings. But the fixtures in schools are not watched as closely as fixtures in our own houses.

MR. NEWSOM. Some years ago when I had charge of the Lynn, Mass., Water Department, I was fortunate in getting the city council to pass a favorable regulation in that respect. They gave the water commissioner the right to set a reasonable figure for the use of water in any public building, and any water that was used in excess of that reasonable figure was paid for at regular metered rates. This scheme was effective in preventing waste.

WILLIAM A. MACKENZIE.* I would like to ask Mr. Newsom whether there is a uniform basis of guaranty for water-works extensions in the different states in which his water companies operate.

MR. NEWSOM. There is no uniform method in vogue. The various methods include all the possible schemes that have ever been heard of. In some states, under the regulations of the utilities commissions, no standard requirement for return on extensions can be enforced. The situation depends entirely upon the financial condition of the individual company. If a company is obviously earning less money than it is entitled to, a rather strict requirement for the carrying charges on a given extension can be made. Upon the other hand, if a company is earning approximately what it is entitled to and if an individual extension will not carry itself, the company will probably have to install it on order of the commission, because they view the situation from the standpoint of the earnings of the company as a whole. There are a few companies that have been successful in carrying out a rather strict method of guaranty. In some cases the developer is required to deposit the entire cost of construction carrying water into the territory which he wants served. When the revenue equals 15 per cent. of the gross expenditure, the entire amount is refunded to the original developer. In other cases the refunds are made as fast as customers connect to the lines, the refunds being based on the various sizes of services and hydrant installations. It is a constant struggle in privately owned, as it is in municipally owned plants to stave off extensions from which the return

*City Engineer, Wallingford, Conn.

is meager and where the burden is thrown on the balance of the plant. I have not found any satisfactory solution of this problem.

MR. BRISTOL. I would like to ask Mr. Newsom how the expenses of the companies before they were consolidated compare with the expenses after consolidation, including the holding-company expense.

MR. NEWSOM. A general answer would be that in large properties, plants having gross revenues of $50 000 a year or more, it is usually possible to make a reduction in total operating expenses. In small plants, when they are included in a group, the operating expenses are likely to be somewhat higher. That is due principally to the fact that methods of accounting in small plants, previously individually owned, are usually simple. Quite often it is more or less a memorandum matter during the year, an auditor being brought in at the end of the year to make an annual report which can be filed with the utility commission and the tax authorities. Whereas when a small plant comes into a group, because it is necessary for the group as a whole to know where it stands at the end of each month, the small plant must make the same detailed report of its financial transactions as does the large one. The cost of the additional accounting in a small plant is likely to be as much as or perhaps a little more than can be saved by economies in operation and reductions in salaries of officers and the elimination of directors' fees.

MR. BRISTOL. When the cost of the holding company is added, is the total operating cost, including the holding company, more than it was before?

MR. NEWSOM. No; the total of the group as a whole is less, including the holding company. If that were not the case, there would be no point in putting them together.

MR. BRISTOL. Unless you can get higher rates.

MR. NEWSOM. Even if you got a higher rate, it would not serve the purpose because you would merely be taking the extra money as revenue and paying it out again as additional expense. But the ability to reduce expenses in a group as a whole depends, in my opinion, on the proper balance of large plants and small plants. If you have too many small plants you can't get the results that you can when you have a lot of large ones in the group.

RUPERT W. WIGMORE.* I would like to ask what elements enter into the establishment of a standby, or ready-to-serve charge. Take a factory that has practically all the fire protection and process water it needs but wants a water connection in case of emergency.

MR. NEWSOM. It is next to impossible to justify a charge for standby service, commensurate with the value of that service to the plant, on the basis of any schedule of fixed charges including only those that have been added as a result of the service in question. The fixed charges on the service line and meter, the cost of reading and billing and things of that sort will

*Commissioner of Water, St. John, N. B.

amount to very little. On the other hand, there is an element of cost which extends back through the system to the pumping station and the reservoirs. But it is almost impossible to convince the consumer who is asking for an emergency service that he should contribute towards those larger elements in the plant. It comes down usually to a question of reaching a figure which is satisfactory to the applicant, using as an argument a comparison of the value that he will receive and what he would have to expend elsewhere and in other ways to obtain the same protection.

MR. WIGMORE. I believe that Springfield has a connection with West Springfield, and maybe one or two other towns, that do not take much water, but for which there is a standby charge.

MR. CARLTON. There is a fixed charge of a certain amount which entitles the town to a definite quantity of water throughout the year. The town has to pay this charge, usually, on the first day of January, and if it has used less water during that year a deduction is made, if more an additional bill is rendered. There is now only one town on our system that is so connected, and every year it uses a certain amount of water to make up for the charge.

MR. BRISTOL. Do you pay taxes in other towns?

MR. CARLTON. Yes.

MR. BRISTOL. Under the same conditions as other people?

MR. CARLTON. When the original bill establishing the water supply was passed by the Legislature it was so worded that the department was to pay taxes on property based on the assessed valuation for three years previous to the taking; whenever new property is acquired the assessors of the town in which it lies furnish a certificate, sworn to by the assessors, of the valuation of the property for the three years preceding. While the tax rate varies, the valuation remains constant.

MR. BRISTOL. You do not have to pay taxes on the improvements such as pipe lines?

MR. CARLTON. We do not. In the legislative bill that authorized the Cobble Mountain project, the town of Granville was given the right to tax the department for the value of the power station, and the town of Russel, was also allowed a certain amount of valuation for taxation.

A MEMBER. Mr. Carlton in his remarks made some mention of the water lien law. I wonder to what extent Springfield has gone into that.

MR. CARLTON. The lien law was adopted by the City of Springfield in 1924, but it was not put into operation until last year. There were several unpaid accounts that were of long standing, and very little success had been attained in collecting them, so the department decided to place liens on these properties. No approved form had been drawn up to be filed in the Registry of Deeds and no warrant to be committed to the city collector. These forms were prepared and approved by the city solicitor; then we filed liens. There is a hotel in Springfield that went into the hands of a receiver, whose bill for water consumed previous to this action was

still unpaid. When the notice was sent that the water was to be shut off for non-payment of bills, the receiver claimed that, being a Federal agent, no one could in any way interfere with the operation of the property while it was in his hands. The city solicitor recommended that we place a lien on this property, in place of shutting off the supply. This was the first lien to be filed by the Springfield Water Department.

The first month that the department started to file liens, I believe there were something like forty that were approved by the board, but on receipt of the notice that a lien was to be placed approximately thirty-six owners paid their bills. We only had to file about four liens at that time. That ratio would probably hold true for every month. As soon as the owner actually receives a notice that a lien is to be placed, if the bill is not paid within ten days, the money is usually forthcoming.

MR. DAVIS. May I ask whether the water department avails itself of the services of the city solicitor?

MR. CARLTON. We have in the employ of the water department an attorney who was formerly the city solicitor. During his term of office some cases were started; consequently the water department has retained him for those cases. We rely wholly on the city solicitor's office for other legal services.

MR. DAVIS. May I also ask if your depreciation reserve is an actual, available fund, or only a book account?

MR. CARLTON. It is only a book account.

A MEMBER. Does the owner pay the entire cost of the service?

MR. CARLTON. The owner pays the entire cost including labor, materials and the meter.

A MEMBER. Do you make a charge for cleaning services?

MR. CARLTON. We charge $3 for cleaning services, if no digging is required. Most of the service lines are straight and connected rigidly with the main. After two or three years of experience with cleaning services at that price we find that we are just breaking even. If the service has to be dug up the entire cost for the work is charged to the owner.

MR. HEFFERNAN. Speaking for the small self-sustaining municipal department,— the town of Milton has a population of about 18 000, about 4 500 services and about 80 miles of pipe — all water is charged for in all municipal buildings, and the different departments pay for the water. Nobody has the right to use a hydrant unless a meter is attached; the water is charged according to the meter reading.

To make the department self-sustaining we had to adopt the following practice: Our hydrant charge is $35 a year. That is the only amount for which we ask an appropriation in town meeting. We charge for the service from the street main to the cellar, and also for the meter, plus the cost of repairing the street paving. The town furnishes a ¾-in. meter at the cost of $10; if a larger meter is desired the difference between the cost of the ¾-in. meter and the meter of the size required must be paid. With a set-

back of about 25 ft. the charge for the service is $70 or $75; that is a pretty expensive charge. But by making this charge, the department becomes self-sustaining. It gets receipts and has to pay all expenses. Main-construction work is done through a bond, usually, and provided extensions of street mains are made, the town puts in a 6-in. pipe on a guaranty of 6 per cent. of the estimated cost for five years. Deposit is made of one-third of the estimated cost of the work. If the required amount is received before the end of five years, the money is refunded.

MR. GIFFORD. Does the Milton consumer pay the actual cost of the service from the main to inside the cellar?

MR. HEFFERNAN. A sum of 25 per cent. is added to the cost.

PRESIDENT ELLIS. Mr. Heffernan did not tell us whether or not his department pays taxes to the town of Milton.

MR. HEFFERNAN. It does not.

PRESIDENT ELLIS. I would like to ask Mr. Carlton how the repair of meters is handled. Is it charged to the owner, and in case of the refusal of the owner of the meter to allow the department to take it out for servicing is the department at all handicapped?

MR. CARLTON. The department stands the cost of maintaining the meter under ordinary use. If it is injured or damaged through backing up of hot water or through freezing and needs repairs the owner is charged for the entire repair bill. Only seldom does anybody object to the removal of the meter for duty test or for inspection. I do not remember a case where that question has arisen.

MR. E. T. CRANCH. Do you always put the same meter back in the same premises?

MR. CARLTON. The meter belongs to the property; so of course the same meter has to go back into the house.

PRESIDENT ELLIS. In that connection I would like to ask Mr. Newsom if it is not true that a private company has to own its own registering devices.

MR. NEWSOM. That is true. There are some cases in which the consumers pay the cost of the service line, but in no case that I recall do they pay for the meter. In fact, the company owns the meter and can do with it as it sees fit in regard to replacement and repair. This is of considerable advantage and makes handling cheaper. Where consumers pay for service lines, the investment in service lines is set up on the capital account as though the lines were paid for by the company. An offset entry is then made on the liability side of the balance sheet in the form of contributions. How is this matter handled in Springfield?

MR. CARLTON. It is handled as a sales charge. As the money is received, it is credited to that charge.

MR. NEWSOM. Does your $16 000 000 valuation include any services?

MR. CARLTON. No, it does not.

SAMUEL H. MACKENZIE.* How do you clean your services?

*Superintendent, Southington, Conn.

MR. CARLTON. We have used a Staples cleaner for several years with good success. We have designed and adopted a different style of knife than the one that originally came with the cleaner, but the rods and stuffing-box connections are the Staples equipment.

L. H. ENSLOW.* If the consumer who is to own his own meter does not like the make of meter that is given him and wants to use a different meter, what is the answer?

MR. CARLTON. He can, but of course the meter must be one that is approved by the department.

HAROLD W. GRISWOLD.† Messrs. Newsom, Carlton and Heffernan have all stated that the consumer pays the cost of the service, and in some cases the cost plus. The mains are not always in the center of the street, so that in many cases a consumer on one side of the street would pay perhaps twice or three times as much for the same service as his neighbor on the other side of the street. Has that question come up, and what is the answer?

MR. HEFFERNAN. If the street is 40 ft. wide and the main is on the same side as the house, 7 ft. from the center, the owner would be charged for 13 ft.; if the main is on the other side he is charged for 27 ft. of service pipe. If the street is 60 or 80 ft. wide we take the middle of the road.

WILLIAM B. DUFFY.‡ On our services we make a charge which covers the cost from the center of the pipe to the property line. There is a charge of 70 cents a foot from the property line to the cellar for ¾-in. services, and 80 cents on 1-in. services. There are no complaints.

MR. WIGMORE. I am very much interested in the paper read by Mr. Carlton because his organization is quite similar to our own. We have about 10 000 services, with a revenue of about $260 000. In connection with the carrying of the service pipe to the property line, the city runs every service pipe to the property line. In the case of the larger services the owner pays the actual cost of labor and materials.

Up to a few years ago we had a surplus of about $50 000, which we were allowed to build up as a reserve fund for renewing old mains. Then there was tacked on to the water department the cost of the sinking fund on sewer bonds, and also sewer maintenance. This about equals the amount of our surplus. I would like to ask Mr. Carlton what he is allowed to do with his surplus.

MR. CARLTON. Theoretically the department is not supposed to have a surplus. I believe the law states that if a municipal water department is building up a surplus, it must reduce its rates. The law does allow, however, a reserve fund to be set up for deferred work if there actually is such work which should be performed; as a rule at the end of the year the money that has accumulated is set aside in this reserve fund. At Springfield it

*Editor, Water Works and Sewerage, New York, N. Y. †Deputy Chief Engineer, Hartford, Conn.
‡Superintendent of Public Works, North Andover, Mass.

reached a figure of about $120 000. Last year the department had to draw on that reserve in order to pay for its operating expenses.

A MEMBER. Do you require a deposit on the service before it is installed?

MR. CARLTON. Yes. A deposit is required when the owner signs the application for the service. For the ordinary 1-in. house service a deposit of $50 is required. If the service is of larger size or unusual length, the superintendent's division estimates the cost and this is the deposit required.

ROGER W. ESTY.* I would like to ask Mr. Newsom how he arrives at the value of hydrant rental; also what has been his experience with the service charge on metered water.

MR NEWSOM. Fire protection charges vary through quite a range. Quite often they have been set some years before by a contract with the municipality,— a franchise contract in many cases. When the charge is made on a hydrant basis it ranges between $25 and $75. In some of the companies in the group the inch-foot charge is in use. In those cases the hydrant charge varies from $5 to $18 per year, and the inch-foot charge in addition varies from about ¾ cent to 1½ cents per inch-foot. Where a charge is as low as $5 per year for hydrants it is not sufficient to carry out the theory of the inch-foot method of charging. The flat charge per year covers the fixed charge and the maintenance of the hydrant and hydrant lateral. The $18 charge is more nearly correct than any lower charge.

In our experience the use of service charges is nearly always unsatisfactory. Actually the service charge plus a charge for water used is the fairest type of charge to the consumer. But it is difficult to make him believe it. If the consumer is paying a service charge plus an output charge and the schedule has been worked out intelligently, he is paying in his service charge those things which are fixed — interest on investment and maintenance of service and meter, and the cost of billing, reading, and so forth — and the output charge covering the balance of costs can be relatively small. Obviously if a consumer wastes much water, he simply pays the additional output charge, which is a much smaller figure than would be the case if there was no service charge. Where there is no service charge there is an item of overhead representing these fixed charges in the rate for each thousand gallons, and when there is a leak the consumer is paying that item several times over. But, as I said before, it is impossible to make consumers believe this. They always think that a service charge represents clear profit to the company, a payment they make for which they get nothing in return. While we have some cases where we are still maintaining service charges, we are getting away from them in favor of a minimum charge which contains a concealed service charge. It is just a psychological situation, but it apparently has to be done that way.

PRESIDENT ELLIS. Most municipal departments have been rather hampered in the enforcement of collections. How do you find this problem?

*Superintendent, Danvers, Mass.

MR. NEWSOM. It probably has been the same with private corporations as with the municipal departments. Incidentally, the private water company is not so free to shut off the water as is the municipal plant. It is a difficult problem in public relations, because the corporation operates for the benefit of the stockholders, and that makes it necessary for it to cater to its consumers. Therefore, even in normal times the question of collections is somewhat complicated. However, it is our experience, from the viewpoint of a large group of utilities, that it is entirely a matter of education. We have one plant south of the Ohio River in which the practice of shutting off water has been strictly enforced; although in that part of the country collections in most types of business are somewhat slower than they are in New England, we probably do our best job of collecting in that plant. That is simply because over a period of years the consumers have learned that water bills must be paid promptly or service will be discontinued. In this present depression, where a consumer has habitually paid bills promptly, is now out of work and has been out of work a long time, and we know that his savings must be exhausted and that he really can't pay the bill, we carry him just the same. Our group is carrying thousands of consumers who have not paid for many months. It is our experience, however, that as soon as these people get work they are inclined to pay their back water-bills promptly, and it encourages one to believe that as times improve a good proportion of those back bills will be paid. Of course, where people have given up their homes and moved away that chance is probably gone.

MR. MACKENZIE. I would like to ask Mr. Newsom if he has found it feasible in making up his water rates to have more than one minimum charge. For instance, you might have a minimum charge of $12 for a single family house, and you could make it $10 for each additional family. I wonder if that has been worked out.

MR. NEWSOM. I know of no case where we have more than one minimum charge, which is based on the number of additional families. We have some rate schedules where the minimum charge is based on the number of fixtures and rooms in a house, and that method, while involving considerable labor in compiling records has much merit, because obviously the value of the service to a house stands in some relation to its size and number of outlets. But I have no experience of applying more than one minimum charge because of the number of families in a house.

WILLIAM A. MACKENZIE.* In answer to this question I would like to say that we have employed the method of applying a minimum in proportion to the number of families, up to four families, at which the minimum stands for a $\frac{5}{8}$-in. meter. This method has worked successfully and has helped materially in holding up the revenue while changing over from the flat rate. There have been few arguments. As an instance, a flat rate would be from $14 to $16 per year, whereas the minimum meter rate for

*Superintendent, Wallingford, Conn.

one family is $12. A charge of $5 is made for each additional family, so that the minimum rate for a 2-family house would be $17, whereas on a flat rate basis the minimum would be $11.50. This method has been in operation about five years.

MR. ESTY. Did I understand, Mr. Carlton, that you apply liens at the end of each month on outstanding accounts? If that is true, how old does the account have to be before the lien is applied?

MR. CARLTON. The law says that the account must be 60 days old before a lien can be placed on the property.

MR. ESTY. At that rate, if you sent a bill out on July 1 and it had not been paid on September 1, you would apply the lien.

MR. CARLTON. No, I would not say that we would do it as soon as that; but it would not be long after that, unless there was some reason why the account had not been settled.

MR. BRISTOL. How do you decide between shutting off the water and putting on a lien? You have the choice, as I understand it.

MR. CARLTON. We do both. The bills are rendered the first of the month. Usually around the 20th the owner receives a second notice if he has not paid the bill. The city collector returns to us about the 8th of the following month a list of all bills remaining unpaid. The department then sends out the final notices, delivering them by our meter inspectors. As soon as possible after that the services are shut off for nonpayment of bills. As soon as the owner pays the bill and the additional charge of $2, the service is put in commission again. There are cases where a man does not have the money and will promise to pay the bill within a day or two. As a courtesy to him the department will put the service in commission again. If he does not live up to his promise, we may in some cases shut the service off again, but in most cases a lien will be placed after 60 days or 90 days.

MR. ESTY. We have been applying liens during the last three years. We had a factory in our town that owed us about $2 200. They did everything they could do to have the charge abated, even calling a special town meeting for that purpose. We applied a lien in their case. Our town has a fine record in tax collections. According to the figures given out by the state on August 1 the amount of outstanding, uncollected taxes for 1932 was a little over 1 per cent., and our town ranked lowest on uncollected taxes out of eighty-three cities and towns with a population of 5 000. On the other hand, in that same list showing the ratio of bonded indebtedness to valuation, we stood in seventy-ninth place. About July 1 we send out notices by registered letter to those accounts that owed bills prior to January 1, and we demand a return receipt. On August 1, those accounts that have not responded by paying the bills are turned over to the town counsel; he prepares a list, files it at the Registry and turns the list over to the tax collector. The list we filed this year, on August 1, for outstanding water bills of 1932 amounted to about $1 700.

MR. CARLTON. The law states that the bill can't be over a year old.

SOME PHASES OF SOUTHERN NEW ENGLAND HYDROLOGY.

BY CALEB MILLS SAVILLE.*

[*Read September 20, 1933.*]

"Nature, immutable in its laws, but forever variable in its phenomena, never repeats itself."

Elisée Réclus, "The Earth."

In the beginning, the author undertook what was expected to be principally a compilation of data from observations of rainfall and run-off conditions occurring on the areas from which The Metropolitan District of Hartford County (Conn., U.S.A.) obtains its water supply.

PURPOSE.

The purpose of this study was to investigate rainfall and run-off conditions on the present and proposed sources of supply to the Hartford Metropolitan District and to ascertain, if possible, their safe capacity during seasons of prolonged drought.

CONCLUSIONS.

1. The conclusion has been reached as a result of this study that the 20-year period of the Nepaug record is insufficient for the purpose and that a record of at least fifty years ordinarily is required in order to attain that end with a reasonable degree of confidence in the result.

2. That water supply conditions during the drought period, so-called, of 1879–1883 were the most severe of any thus far of record in the area under consideration.

3. That periods of drought somewhat more severe than any yet experienced are likely to recur.

4. That in preparing for the water supply of a large or important community, conditions reasonably certain to occur during a 50-year period, at least, should be provided for.

5. That a rainfall record, to be of firm value as a criterion, should have extended over a period of at least thirty-five years to be dependable within 2½ per cent. of normal (plus or minus). See Figure 11.

6. That run-off records for a period of 20 years can be expected to give dependable results hardly closer than 10 to 15 per cent. See Figure 21.

7. That run-off from each watershed is so dependent upon topography, meteorology, geology, vegetative requirements, geographical position and local conditions, that the utmost caution should be used in applying data obtained from one watershed to another.

*Manager and Chief Engineer, Water Bureau, Metropolitan District Commission, Hartford, Conn.

Interest having been aroused by this study, its scope was considerably broadened and some of the data collected are presented herewith in the hope that they may be of some interest to others and possibly stimulate further effort toward the solution of that important class of water-supply problems, dealing with rainfall and allied phenomena.

Rainfall Studies.

The wide variation in conditions which exist on watersheds, makes it impracticable at this time to adduce a general formula for expressing relationship between rainfall and run-off, and except possibly for individual watersheds, one must rely principally on actual experiences for a basis of estimate.

Rainfall history usually is much longer and more reliable than recorded run-off, particularly in the case of the low run-off records during drought periods, added to this, however, is the uncertainty of rainfall records being representative of conditions over the entire watershed.

The most important influence of watershed yield obviously is the amount (or lack) of rain which falls in a given period. While records of rainfall, in this country at least, are available over time periods of 100 years or more, records of run-off unfortunately, except for a very few stations, have been kept generally for periods of not over 20 or 25 years. Notable exceptions are the long records of Sudbury River (58 years), Croton watershed (65 years), Merrimack River (85 years) and Cochituate watershed (70 years).

This condition is referred to later in the paper, and a diagram (Fig. 21) presented from which it is possible to determine to some extent the relative dependability of records of given length.

The writer is of the opinion that in the hands of an experienced water-supply engineer reliable rainfall records are much better indices of capacity of a watershed than are run-off records of less than 25 or 30 years, and that the amount of rainfall during the lowest three or four consecutive years, modified by proper factors to express run-off relationship, is a much safer criterion for estimation of watershed capacity on an unknown area than are run-off records from other streams.

The writer is also of the opinion, that the character of a proposed water-supply reservoir usually has not been given sufficient attention in estimating yield, that is, whether or not there is invisible storage in the material below water level. This matter was referred to by the late Allen Hazen in his monograph on Collection of Water.*

A study of rainfall history indicates that droughts of sufficient severity to affect water supply resources seriously are not of as infrequent occurrence as popular idea conceives, and that the general public is prone readily to forget the past.

*American Civil Engineer's Handbook, Merriman & Wiggin. John Wiley & Sons, New York.

At least three serious droughts have affected Southern New England in the last half century. Theories of probability of exceptional droughts and floods are valuable only as guides to experienced judgment, and droughts are but the antithesis of floods, although somewhat more frequent. In English history of flood happening, the year 1912 saw a flood record at Norwich (England) that had not been exceeded in 300 years. In France a celebrated engineer, in working up flood control on the Seine in 1873, stated that he had "demonstrated that the recurrence of the flood of 1658 under same condition . . . would require thousands of years"; yet that very condition of flooding happened only 37 years later.

Recognition of the need of study and desirability of discussion which would be informative on the value of length of record and the relationship of one period to another has grown steadily during this investigation. The number of rainfall records now being carried along is increasing rapidly as water-supply workers have realized the necessity of this information, but comparatively few of these records as yet have that standing for criteria which can come only from reliable observations extending over a long period. What may be the relative reliability of the shorter records in order to place them in position to be useful, with assurance of their value for deductive purposes, was one of the intentions of this search.

This matter of rainfall records has been referred to considerably in American practice and in the technical press. Particular interest attaches to the report of Edward Burr on Merrimack River conditions[1] and articles by X. H. Goodnough[2] and others on the long term New Bedford record as well as the very valuable compilation of rainfall records by Goodnough appearing from time to time in this JOURNAL.[3]

Two of these articles[4] were the result of a search prompted by need for information regarding reliability of comparatively short records. This is a common difficulty encountered in seeking data for hydrological bases in localities where records are wanting altogether, or cover too short a period to be used with confidence.

The present paper will have served its purpose admirably if it supplies some data applicable to this problem as well as calling to attention events that may be precursors of untoward conditions which reasonably may be expected and for which provision should be made in safeguarding water supply to important communities.

Within the period 1920–30, inclusive, has occurred almost the greatest range in rainfall amount that has been experienced in the 65-year continuous record at the West Hartford (Conn., U.S.A.) station of the Hartford Metropolitan District Water Supply. During the same period the entire country, including Southern New England, has experienced very unusual conditions of drought. For the calendar year 1920, the rainfall was 56.95 in. (the maximum of record for this station); while that for 1930 was 34.11 in.,

[1]Doc. 9, 62nd Congress, 1st Session.
[2]1915, 1921, 1926 and 1930.
[3]*Engineering News*, November 19, 1914.
[4]*Engineering News*, June 24, 1915, pp. 1212 and 1913.

a spread of 22.84 in. The least rainfall of record for this station was 33.64 in. (1883), and the greatest previously reported was 55.81 in. (1869). The extreme range for this station, for calendar periods, is 23.31 in. (56.95—33.64) a difference of only about half an inch (0.47 in.) greater than that of the decade 1920–30, and 53.5 per cent. of the average (43.63 in.) for the years of record. For consecutive periods, other than calendar, the range was from 30.41 in. (July 1879–June 1880) to 61.37 in. (Sept. 1907–Aug. 1908), a difference of 30.96 in. or about one third (32.8 per cent.) greater than the spread for calendar years, and a "dependability" of 2.02 (see p. 369).*

In view of these facts it appears to be probable that within periods of from 10 to 15 years, the total annual rainfall in this locality may reach extremes, the differences of which are at least one half and perhaps nearly three quarters of average annual rainfall.

In this discussion, reference is made particularly to conditions in the north central portion of Connecticut. The facts presented, however, are generally applicable to the region of Southern New England and particularly to the rainfall of that district.

At a later time, it is hoped to present a similar discussion of run-off conditions in the same area. Some reference to that matter is made, but this paper will be confined principally to presentation of rainfall data for purposes of record, yield data being presented for the purpose of rounding out the discussion of the principal subject.

Hartford Watersheds.

There are two watersheds from which the Hartford District obtains its water supply, and a third one used at present for compensation purposes.

1. The *West Hartford* System comprises about 5.3 sq. miles on the easterly slope of Talcott Mountain Ridge, located about six miles west of Hartford.

2. The *Nepaug* System which includes about 31.9 sq. miles, lying a little north of west from Hartford, chiefly in the town of New Hartford, and on a tributary of the Farmington River from the west, about 15 miles from Hartford.

3. The *East Branch* System which is a tributary of the Farmington River from the east, about 20 miles distant from and lying northwest of Hartford, in the towns of Barkhamsted and Hartland, comprising about 62 sq. miles of drainage area, of which about 52 sq. miles now are being further developed to furnish an additional supply to the district.

The general location of these watersheds is shown on Plate I; their general geographical position is about Latitude N. 41° 50′ and Longitude W. 73° 35′. The topographical and geological character of these three watersheds differs considerably.

The West Hartford area lies on the red triassic sandstone of the lower

*Refer also to Rafter and Simons, p. 372.

Connecticut Valley, the slopes being coincident with an uplift from a basalt dike which extends in a north and south direction across Connecticut and into Massachusetts. The portion of the drainage area here considered extends along the easterly slope of this ridge for about six miles, the reservoirs (four in number) for the most part being formed by side-hill dikes of

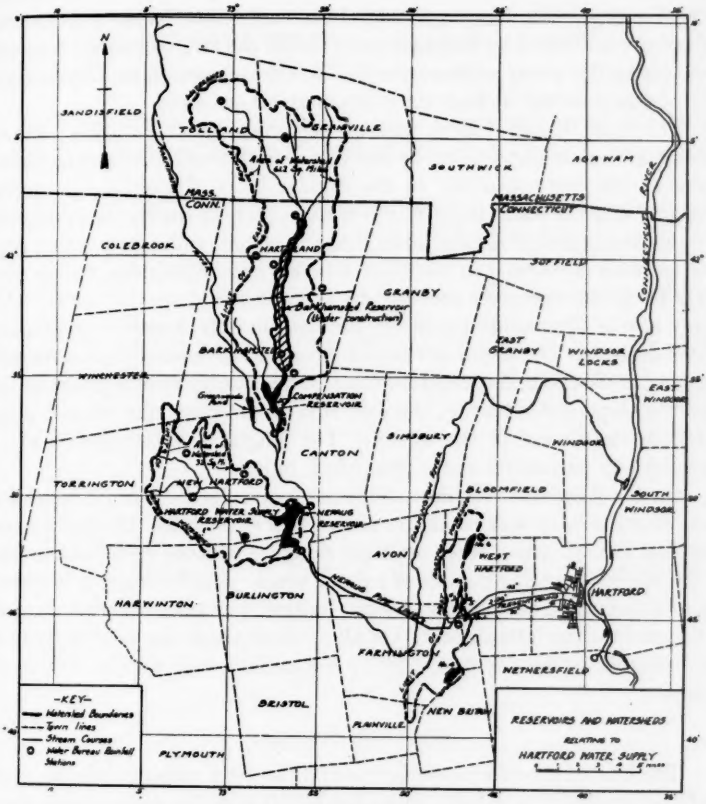


PLATE I.

considerable length, and fed from direct surface run-off and small streams entering along their westerly margins. The top of the ridge of the watershed rises from 800 to 900 ft. above mean sea level, the surface of the several reservoirs at high water being from 260 to 400 ft. above that datum. This area is exposed to northeasterly, east and southerly winds, but is mostly sheltered from those coming from the west.

The Nepaug watershed is roughly oval in shape, with its longer axis lying northwest and southeast, having an extreme length of about nine

miles and a width of about 4½ miles. In general, the area is drained by one principal stream (the Nepaug River), serving an area of about 21 sq. miles, and two smaller streams. Reservoir high water is at el. 485 with surrounding ridges from 900 to 1 200 ft. in extreme height. The country rock is classified mostly as Hartland schist. The area has rather gentle slopes, and is a thoroughly glaciated country, abounding in gravel deposits of the lacustrine and esker type. The Nepaug Reservoir, of about nine billion gallons total capacity, was formed by building dams across the two largest streams and thus raising the water surface over the divide between them. The surface area of this reservoir at high water is about 1.3 sq. miles.

The East Branch Valley, with its beginning about six miles north of "Nepaug," has an almost directly north and south trend; the most northerly limits of the watershed are in the highlands in Massachusetts on the northerly slope of which is the water-supply source of the city of Springfield (Borden Brook and Westfield Little River), about 18 miles west of that city. The extreme elevations in the East Branch watershed ridge rise to over 1 600 ft. in the northerly end and to about 1 200 ft. in the south. This valley also is thoroughly glaciated, the bottom only, however, containing gravel deposits. The slopes are mostly steep and covered with thin residual deposits or débris from ground moraine. The country rock is gneiss on the westerly slope and schist on the east side of the river, the contact being about in the thread of the stream. The length of this valley is about 15 miles and its general width about four miles.

On the West Hartford area, there are four raingages, one of which has been in continuous service at the same place since 1868. On the Nepaug and East Branch areas, there are eight raingage stations each, with several of the records covering periods of twenty years. All of the gages in service are of standard U. S. Weather Bureau pattern, one in each area having an automatic register attachment. On all of these areas, the flow of water in the principal streams is measured by a standard weir with an automatic recorder.

Drought Studies.

The United States as a whole recently has been passing through a period of excessively low rainfall, which has left its mark on water-supply works among other conditions affecting human life and well-being. This New England section has not been entirely immune, although probably not so seriously affected at this time as other portions of the country. The general extent of this drought period over the country has been described by J. C. Hoyt,* and it appears (p. 1828) that of the states east of the Mississippi River, New England rainfall was about 82 per cent. of normal, while other locations received as little as 58 per cent.

From personal correspondence with, and through the courtesy of Professor Oliver L. Fassig, late of the U. S. Weather Bureau, the following

*Jour. Am. Water Works Assn., 23, Nov. 1931.

data are taken from an unpublished manuscript as applicable to general rainfall conditions in the southern New England area:

Rainfall Relations (1881–1930).	Mass.	R. I.	Conn.
Average departure (inches) from normal...	.....	±4.16	(3 states)
Least annual amount.....	32.43	32.83	32.02
Greatest annual amount.....	57.51	63.15	58.99
Extreme annual range, per cent. of normal	.....	±63%	(3 states)
Rainfall "dependability" $\frac{ann.\ max.}{ann.\ min.}$.....	1.77	1.92	1.84

For purposes of comparison, Table 1 is presented herewith, comprising rainfall data from 20 stations in Southern New England and immediate

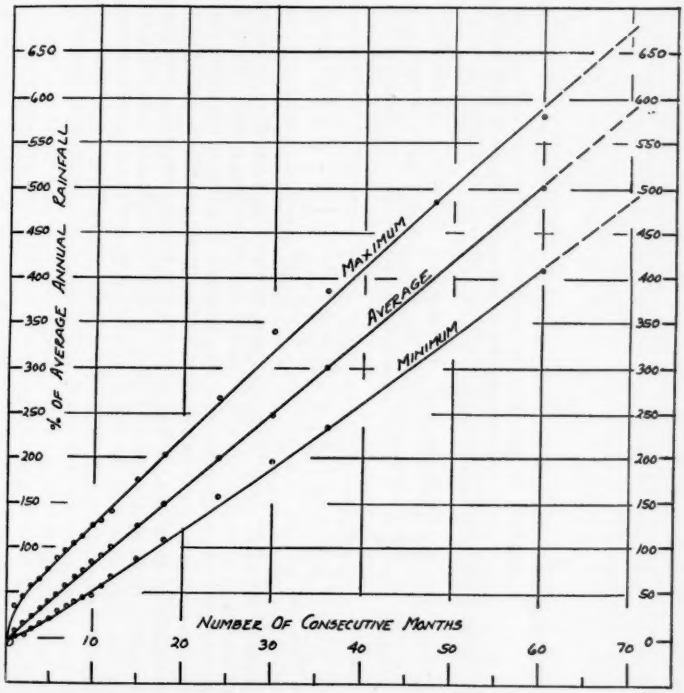


FIG. 1.—MAXIMUM AND MINIMUM RAINFALL AT RESERVOIR NO. 1, WEST HARTFORD, FOR CONSECUTIVE MONTHS EXPRESSED AS PER CENT. OF AVERAGE ANNUAL. The average rainfall for the years of record (1868–1932) was 43.63 in.

locality having some of the longest records of this part of the country. An interesting feature of this compilation is the relative amount of rain received in stated periods of from one to four years of least fall individually and in

TABLE 1.— FLUCTUATION OF RAINFALL AT VARIOUS STATIONS IN SOUTHERN NEW ENGLAND ARRANGED IN RELATION TO THE DEPTH OF RAINFALL, MEAN ANNUAL = UNITY.
Fluctuations Expressed as Percentages of that Amount.

STATION.	Period of Observation.		Average Rainfall Years Record.	Fall of Wettest and Driest Yr.			Av. Fall of 2 Wettest and 2 Driest Cons. Yrs.			Av. Fall of 3 Wettest and 3 Driest Cons. Yrs.			Av. Fall of 4 Wettest and 4 Driest Cons. Yrs.			Number of Yrs. and Av. Fall During Largest Series Cons. Yrs. Above and Below Mean.					Number and Av. Fall of all Yrs. Above and Below Means.				
																Years Above.		Years Below.		Range.	Per cent. of No. of Years.		Average Fall of All Years.		Range.
	Tot.	From To		Max.	Min.	R'ng.	Max.	Min.	R'ng.	Max.	Min.	R'ng.	Max.	Min.	R'ng.	No.*	Av.	No.*	Av.		Above.	Below.	Above.	Below.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1. Croton Res.	64	1868–1931	47.79	133.4	75.9	57.5	**123.3**	**80.9**	**42.4**	122.8	83.1	39.7	118.6	**87.9**	**30.7**	**5**	115.1	7	90.4	24.7	46.9	53.1	110.9	90.3	20.6
2. Middletown, Ct.	73	1859–1931	46.48	143.2	73.1	70.1	134.0	78.4	55.6	123.9	82.9	41.0	121.2	83.2	38.0	6	117.3	9	87.4	29.9	46.6	53.4	**117.3**	87.4	**29.9**
3. New Haven	74	1858–1931	46.41	**129.8**	72.7	57.1	129.3	75.5	53.8	121.4	80.5	40.9	118.0	85.2	32.8	7	112.3	6	91.9	20.4	45.9	54.1	112.5	89.4	23.1
4. New Bedford	118	1814–1931	46.01	142.0	**60.9**	81.1	141.3	77.3	64.0	138.6	**83.9**	54.7	130.7	85.6	45.1	9	**108.0**	11	92.5	**15.5**	44.1	55.9	112.3	90.3	22.0
5. L. Cochituate	80	1852–1931	45.25	**153.1**	69.0	84.1	132.9	79.0	53.9	125.5	79.2	46.3	128.5	80.4	48.1	9	117.2	**17**	88.5	28.7	46.3	53.7	113.4	88.5	24.9
6. Providence	100	1832–1931	44.96	141.2	67.9	73.3	132.7	76.6	56.1	126.3	**74.4**	51.9	124.1	76.9	47.2	10	111.5	9	82.0	29.5	50.0	50.0	111.6	88.4	23.2
7. New York Vic.	96	1836–1931	44.87	145.9	61.4	84.5	132.3	76.4	55.9	127.0	78.6	48.4	130.3	81.2	49.1	13	119.8	9	84.3	35.5	45.8	54.2	115.8	**86.7**	29.1
8. Boston	114	1818–1931	44.44	152.3	61.2	**91.1**	146.7	**72.1**	74.6	**142.6**	81.2	61.4	**138.3**	80.9	**57.4**	**18**	125.5	11	87.9	37.6	44.7	55.3	116.0	87.1	28.9
9. Worcester	91	1841–1931	44.27	138.9	69.1	69.8	137.9	73.1	64.8	136.5	80.0	56.5	135.5	82.6	52.9	6	**128.3**	9	87.6	**40.7**	**42.9**	**57.1**	113.1	90.2	22.9
10. New London	61	1871–1931	43.95	138.1	68.4	69.7	124.1	78.8	45.3	120.8	81.9	38.9	117.9	82.5	35.4	8	113.9	7	86.3	27.6	45.9	54.1	112.0	89.8	22.2
11. Amherst	96	1836–1931	43.82	132.5	70.0	62.5	127.0	79.7	47.3	**117.5**	80.6	**36.9**	**116.7**	84.7	32.0	5	114.0	7	**93.6**	20.4	46.9	53.1	**110.7**	**90.6**	**20.1**
12. Springfield	84	1848–1931	43.59	133.0	70.8	62.2	124.2	75.3	48.9	121.7	79.2	42.5	120.2	82.0	38.2	10	112.4	11	87.1	25.3	**51.2**	**48.8**	111.2	88.3	22.9
13. West Hartford	64	1868–1931	43.54	130.8	**77.3**	**53.5**	125.2	80.2	45.0	125.7	82.4	43.3	121.4	83.0	38.4	7	111.8	6	84.3	27.5	48.4	51.6	111.5	89.1	22.4
14. Cambridge	91	1841–1931	43.04	137.9	70.0	67.9	132.0	76.6	55.4	127.0	79.4	47.6	125.8	80.4	45.4	11	121.1	13	88.1	33.0	45.1	54.9	113.8	88.7	25.1
15. Waltham	107	1825–1931	42.08	147.6	67.5	80.1	132.5	74.1	58.4	128.8	79.3	49.5	124.6	78.3	46.3	8	115.4	9	92.6	22.8	47.7	52.3	112.0	89.1	22.9
16. Lawrence	76	1856–1931	42.19	139.1	70.6	68.5	136.5	75.3	61.2	123.8	78.3	45.5	121.0	78.7	42.3	7	114.8	12	85.2	29.6	43.4	56.6	114.1	89.2	24.9
17. Fitchburg	67	1865–1931	41.36	144.1	66.4	77.7	139.0	73.5	66.1	130.6	76.2	54.4	128.5	76.5	52.0	8	119.6	12	88.4	31.2	46.3	53.7	114.6	87.5	27.1
18. Lowell	106	1826–1931	41.26	145.0	72.2	72.8	135.3	76.0	59.3	127.4	76.3	51.1	125.1	78.0	47.1	11	108.5	13	83.3	25.2	47.2	52.8	113.4	88.1	25.3
19. Concord (N.H.)	73	1859–1931	37.93	143.2	68.8	74.4	134.4	75.4	59.0	127.1	76.8	50.3	125.0	80.1	44.9	6	117.3	11	87.3	30.0	47.9	52.1	113.4	87.7	25.7
20. Albany (N.Y.)	106	1826–1931	37.10	153.0	68.8	84.2	**151.8**	75.7	**76.1**	140.9	76.4	**64.5**	133.9	78.9	55.0	10	115.8	12	81.7	34.1	50.0	50.0	113.0	86.2	26.8

17. Fitchburg	67	1865–1931	41.38	144.7	68.2	77.6	138.2	77.0	61.2	129.1	77.6	51.5	126.2	79.1	47.1	11	109.2	13	83.3	25.2	47.2	52.8	113.4	88.1	25.3
18. Lowell	106	1826–1931	41.26	145.0	72.2	72.8	135.3	76.0	59.3	127.4	76.3	51.1	125.1	78.0	47.1	11	108.5	13	83.3	25.2	47.2	52.8	113.4	88.1	25.3
19. Concord (N.H.)	73	1859–1931	37.93	143.2	68.8	74.4	134.4	75.4	59.0	127.1	76.8	50.3	125.0	80.1	44.9	6	117.3	11	87.3	30.0	47.9	52.1	113.4	87.7	25.7
20. Albany (N.Y.)	106	1826–1931	37.10	153.0	68.8	84.2	**151.8**	75.7	**76.1**	140.9	76.4	**64.5**	133.9	78.9	55.0	10	115.8	12	**81.7**	34.1	50.0	50.0	113.2	86.9	26.3
Total = 1741		Averages —		141.2	69.1	72.1	133.6	76.5	57.1	127.8	79.5	48.3	125.3	81.4	43.9	8.7	116.0	10.0	87.5	28.5	46.7	53.3	113.1	88.6	24.5
Extreme Differences		Plus		11.9	8.2	19.0	18.2	4.4	19.0	14.8	4.4	16.2	13.0	6.5	13.5	9.3	12.3	7.0	6.1	12.2	4.5	3.8	4.2	2.0	5.4
		Minus		11.4	8.2	18.6	10.3	4.4	14.7	10.3	5.1	11.4	8.6	4.9	13.2	3.7	8.0	4.0	5.8	13.0	3.8	4.5	2.4	1.9	4.4
Average Differences		Plus		5.7	3.4	8.2	6.1	2.1	7.7	3.7	2.3	6.0	6.1	2.7	5.3	2.5	4.8	2.3	2.7	4.2	1.8	1.5	1.4	1.1	2.2
		Minus		6.4	3.1	8.2	4.9	1.7	6.2	8.5	1.9	6.0	4.1	2.3	7.9	2.1	3.2	2.3	2.6	5.2	1.5	1.8	1.5	0.9	2.3

Source of Method. The method and form of this table is similar to the study by Sir Alexander Binnie, in his paper "Average Annual Rainfall" — Reference Proc. Inst. C. E., 109 (1892)* p. 89 et seq. There is however one fundamental difference — in Mr. Binnie's paper, consecutive periods of years were used in determining the maximum and minimum one, two, three, and four year periods while in this study running averages were used which covered all combinations of years also of course different stations and different periods were used in each study. *(Similar to table IX — Binnie.)

Explanation of Method. In the entire study percentages are used in place of the actual rainfall, all being referred to the average annual rainfall for each respective station as unity or 100%. These averages may be found in column 4.

Fall of Wettest and Driest Year. Columns 5, 6, 7. In column 5, the maximum rainfall for any calendar year is selected from each station and listed as a percentage of its respective station average. Similarly with column 6 — the minimum year is selected at each station and listed as a percentage of the respective station average. Column 7 — the range or difference between the maximum and minimum — columns 5 and 6.

Average Fall of 2 Wettest and 2 Driest Years. Columns 8, 9, 10. These columns are exactly the same as columns 5, 6, 7 except that the average of 2 maximum and 2 minimum (consecutive) years is used. In the same manner the fall of 3 and 4 years is averaged and referred to the respective station average. (Columns 11-16 incl.)

Number of Years of Average Fall during longest series above and below. Columns 17-18: Years above. In column 17 may be found the longest number of consecutive years during which the annual rainfall was above the station average. In column 18 is listed the percentage of the average, of these longest consecutive periods, referred to the average annual for each respective station. Columns 19-20: Years below. Similar to columns 17-18, only based longest number of minimum consecutive years of rainfall and their average with relation to the average annual for each station. Column 21: Range — the difference between column 18 and column 20.

Number and Average Fall of all years above and below Mean. Columns 22-23: Per cent. of number of years above and below. The actual number of years above and below each respective station average is listed in percentage of the total number of years of record at each respective station. Thus the sum of the two percentages should equal 100%.

Columns 24-25. Average fall of all years above and below respective station averages. Average of percentage will not necessarily be 100% unless weights are used.

Column 26. The range or difference between 24 and 25.

Summaries. *The Average in each column — straight arithmetic average of each column. (Averages starred below refer to this average.)

Extreme Differences. Plus — In each column, designated by boldface may be found the extremes for that column. The extreme difference plus is the difference between the maximum and average*. *Minus.* — the difference between the minimum and the average.*

Average Differences. Plus. — All percentages *above the average** in each column are averaged and the difference between the resultant average and the column average* is listed as the Average Difference Plus. *Minus.* — Similarly with the Average Difference Minus — all percentages below the average* in each column are averaged and the difference between the resultant average and the column average* is listed as the Average Difference Minus.

combination. Figure 1 gives in diagrammatic form the relationship of averages, and maximum and minimum rainfall for the West Hartford station.

If the averages at the bottom of Column 5, Table 1, are halved, the result is consistent with the observations of Simons and Rafter, mentioned elsewhere in this paper. (See p. 374.)

Confirming this statement, the following ratios of minimum to maximum precipitation are presented from Table 1.

1.	Dryest to wettest	69.1/141.2 = 48.9%
2.	Two dryest to two wettest	76.5/133.6 = 57.2%
3.	Three dryest to three wettest	79.5/127.8 = 62.2%
4.	Four dryest to four wettest	81.4/125.3 = 64.9%

These figures are consistent with those of Dr. Fassig given previously: The ratio of minimum to average (mean) is:

1.	Dryest year	69.1%
2.	Two dryest years	76.5%
3.	Three dryest years	79.5%
4.	Four dryest years	81.4%

In this connection it is of interest to note that the mean 3-year dryest period of 79.5 per cent. of all the station averages here given corresponds to the 80 per cent. average used in English water-supply studies in establishing the low-flow (3-year period) yield provided for in watershed yield studies. In the absence of long-period records of watershed yield, recognized procedure with English engineers is to take the average annual rainfall on the watershed, or its estimate if records are not at hand, then depreciate this by 80 per cent. to arrive at the amount of rainfall to be relied on during a period of three consecutive dry years. From this result a flat deduction usually of 14 in. is made to cover natural losses due to evaporation and absorption. The remainder thus obtained is called the "reliable" or "available" yield.

Drought does not necessarily mean rainless weather; it may mean as well a period of weather during which the rainfall is insufficient for the requirements of vegetation and evaporation when a demand is made on ground storage to supply the deficiency, resulting in diminished stream flow.

Normal rainfall conditions in this section of the country are shown on Plate II, taken from the U. S. Weather Bureau map of "Normal Annual Precipitation."

It is pertinent to mention here that the word drought as ordinarily considered is relative and the use to which water is put, usually determines the condition. In the mind of the agriculturist "drought" refers to dearth of rain during the immediate growing season, *i.e.*, June to September; "drought" in connection with water supply means impairment of available supply and ordinarily results from lack of rain during the previous storage and replenishing periods. The drought very often is loosely used, and in common parlance refers to any condition where lack of water causes remark,

particularly that condition which is annoying or harmful to individual interests. By definition, drought is "long continued dry weather; want of rain,"* and "lack of rain or water, especially such dryness of weather or climate as affects the earth and prevents growth of plants."† In English

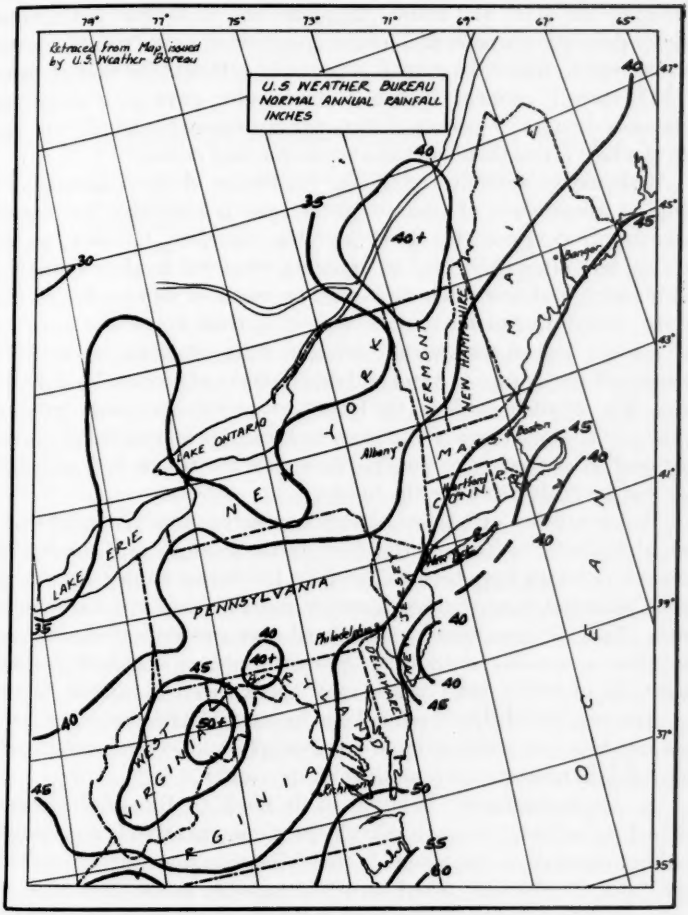


PLATE II.

meteorological use, an absolute drought is a period of fifteen or more consecutive days on no one of which 0.01 in. of rain or more is recorded, and a partial drought "a period of twenty-nine or more consecutive days, during which the mean rainfall does not exceed 0.01 in. per day." A. J. Henry‡

*Webster's Dictionary. †Standard Dictionary.
‡U. S. Dept. Agric. Bull. Q, Climatology of the U. S.

in 1906 proposed and used the following definition: "a drought is considered to exist whenever the rainfall of a period of twenty-one days or longer is but thirty per cent. of the average for the time and place." The latest authoritative definition in this country is that of the U. S. Weather Bureau,* "Drought: — a lack of rainfall so great and long continued as to affect injuriously the plant and animal kingdoms and to deplete water supplies both for domestic purposes and for the operation of power plants, especially in those regions where the rainfall is normally sufficient for such purposes." G. J. Symons,† eminent British Meteorologist, gave as a definition of "engineers drought," "periods of three or more successive months the aggregate of which is less than half the average for that period."

It should go without saying that knowledge of the frequency of unfavorable occurrences of climatic phenomena is necessary for successful water-supply development. It is desirable, therefore, to know, so far as possible, how often there may be droughts, what will be their continuation and severity, and how often there may be excess of rain producing floods. On the correct application of data concerning these matters of meteorological science, depend for accurate solution those problems which are concerned with the storage of water and development of proposed water-supply areas. The only safe guide for the future is that which has been experienced in the actual happenings of the past, and from these, combined with good judgment as accurately as possible to deduce the trends and probabilities that can be anticipated for the future.

Water utilities and those persons connected with this matter in the United States are extremely fortunate in the possession of the records of stream flow which have been collected by the Water Supply Branch of the U. S. Geological Survey; these, however, must be used with care and judgment. Many of these records now extend over a period sufficiently long to give them a standing warranting their usefulness as standards in judging conditions of water yield which may be expected in similar locations. Nevertheless, knowledge of rainfall and its vagaries is and must be the only sure foundation on which to build water-supply works of importance, with a reasonable expectation of confidence in the results.

In his monograph "Relation of Rainfall to Run-off," George W. Rafter‡ stated that "as a general rule the minimum rainfall may be placed at about one-half the maximum," qualifying this, however, by the remark that "near the seacoast, where supply of moisture in the air is more nearly constant, there is less variation than in the interior." A similar observation was made also by G. J. Symons§ in 1892, that "A rule used to be quoted, and it was approximately, but not absolutely right, that the rainfall in the wettest year would be twice what it was in the dryest year"; (note data for West Hartford, pp. 371 and 372, and Table 1). Symons remarked also that

*Preliminary report, Chief of Weather Bur., Aug. 31, 1931, p. 4.
†British Floods and Droughts, p. 173.
‡U. S. Geol. Survey, Wat. Sup. and Irr. Paper 80, p. 12.
§Discussion by Sir Alexander Binnie, Proc. Inst. Civil Eng., 109, (1892), p. 58.

if such a period as that in England from 1738 to 1760 were again to be experienced, "There was not a town or city in the United Kingdom in which the supply of gravitation water works would not break down."

In the case of the general locality under present discussion, one half the maximum rainfall thus far experienced is 28.48 in. or 4.83 in. less than the low (calendar period) so far recorded.

A. J. Henry,* in commenting on such conditions, proposed the following general relationship:

RATIO OF WETTEST AND DRYEST YEARS TO THE MEAN RAINFALL.

Mean Rainfall. Inches	Average of Wettest Years. %	Average of Dryest Years. %
50–60	142	70
40–50	143	64
30–40	154	64
5–50	178	55

With a normal rainfall of 43.845 in. at West Hartford Station, the ratios given in the table would result in probable maximum and minimum values respectively of 62.7 in. and 28.1 in., the latter amount checking closely that obtained by the previous rule. (See p. 398 for actual maximum and minimum of record). The spread between high and low is, however, somewhat greater than that obtained by the observations of Rafter and Symons. It matters little, however, to a parched country that the "average" rainfall is sufficient for its needs, when the reserve in storage is insufficient to carry over on account of a continuing low rainfall period.

The inference from the statements of qualified investigators previously quoted is that much drier periods than at present recorded are reasonably to be expected in this part of the country.

Figure 2 gives the annual rainfall at Reservoir No. 1, West Hartford, for the years of record (1868–1932) both in inches of precipitation and in percentage of normal.† From these, and from Table 2 it is evident that while low and high rainfall periods are often bunched, there are frequent departures from this arrangement. For example: while the rainfall of the calendar period 1879–1883 comprised the lowest year, and the third, fourth and fifth lowest consecutive years, the period 1930–1931 included the lowest two years in consecutive calendar order, the average of this period being only 0.68 in. more than the actual (not calendar) minimum twelve months period (Oct. 1879–Sept. 1881).

Figure 3 is presented for the purpose of more clearly demonstrating these relationships, corresponding figures for which appear in Table 3 for West Hartford, and similar figures are given in Table 4 for Amherst, Mass. Table 5, taken from the probability curves given in Figures 4 and 5 and similar plots, gives some idea of the average frequency of periods of the low

*U. S. Weather Bureau Bull. "D," p. 41. †See p. 376.

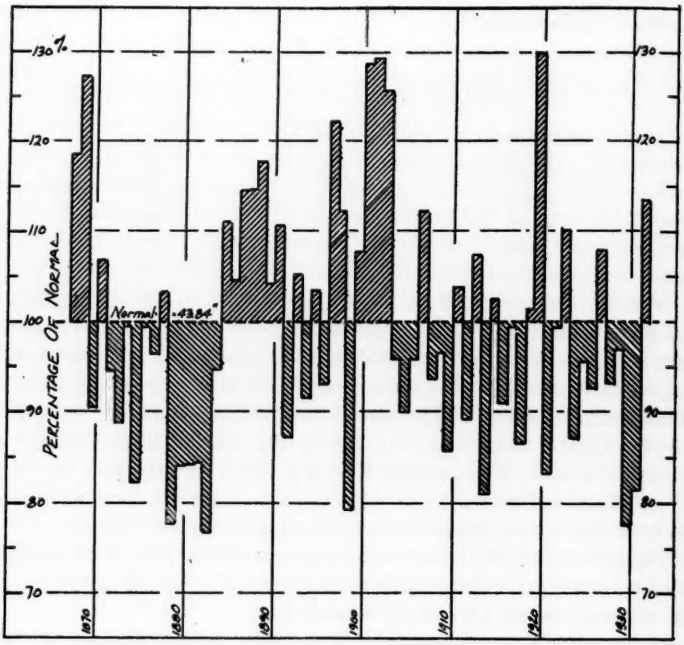


FIG. 2.— PERCENTAGE OF ANNUAL RAINFALL AT RESERVOIR NO. 1, WEST HARTFORD, TO 50-YEAR NORMAL. (1878–1927 = 43.84 in.). Except for the two years 1871 and 1878, the rainfall at this station was below normal for 15 years (1870–1884 incl.).

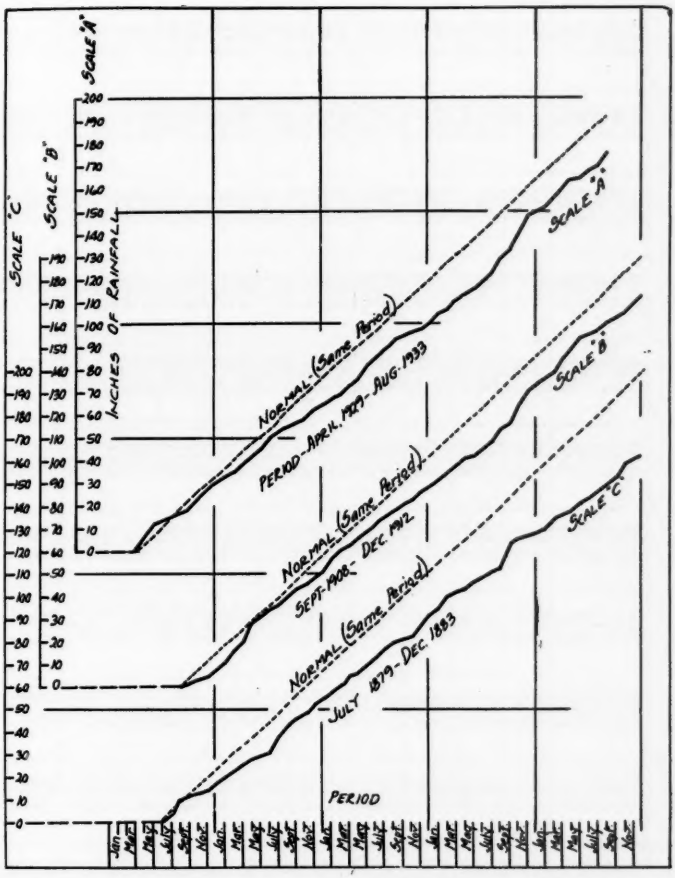


FIG. 3.— RAINFALL AT RESERVOIR NO. 1, WEST HARTFORD; COMPARISON OF MASS DIAGRAMS FOR THREE DRY PERIODS.

TABLE 2.— RAINFALL IN INCHES FOR EACH MONTH, RECORDED AT RESERVOIR NO. 1, WEST HARTFORD.

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1868	3.23	1.75	2.75	4.95	**9.10**	4.50	1.83	7.15	9.98	0.77	4.45	1.48	52.00
1869	3.60	3.94	6.39	1.63	4.86	7.76	1.33	1.07	3.46	13.33	3.40	5.04	55.81
1870	4.84	6.15	5.26	4.24	1.15	4.18	1.36	1.64	0.70	4.86	3.40	1.95	39.73
1871	2.26	3.20	5.09	2.07	4.78	6.16	2.91	7.02	1.24	6.49	3.60	1.99	46.81
1872	1.08	1.94	3.29	1.35	3.41	4.26	6.08	6.50	3.95	2.60	4.27	2.80	41.53
1873	4.07	2.35	2.20	3.45	6.25	**0.15**	1.98	6.02	2.56	3.62	2.43	3.87	38.95
1874	5.57	2.75	1.15	6.49	3.52	4.86	5.22	6.50	2.83	1.12	2.30	1.35	43.66
1875	2.06	3.40	3.31	3.15	1.18	2.59	2.18	7.86	1.40	3.60	4.37	0.92	36.02
1876	1.25	4.29	8.47	2.97	4.45	2.54	5.94	**0.25**	4.43	1.00	3.56	4.45	43.60
1877	2.83	1.09	**9.38**	2.18	0.43	5.29	3.09	3.63	0.37	7.21	**6.09**	**0.67**	42.26
1878	5.78	3.95	3.00	4.59	2.32	4.11	2.22	3.75	2.22	2.22	5.25	5.94	45.35
1879	1.71	3.05	3.03	4.00	1.60	3.74	3.36	6.50	1.70	0.73	1.61	3.08	34.11
1880	2.78	3.06	3.00	1.83	0.73	2.03	7.02	5.20	2.98	1.60	4.80	1.85	36.88
1881	3.80	2.30	4.70	1.16	3.83	2.35	4.80	3.00	**1.25**	1.86	4.80	4.06	36.91
1882	2.42	5.77	2.60	1.15	3.42	1.31	3.22	1.15	10.88	2.69	0.85	1.58	37.04
1883	1.95	4.42	1.65	1.24	2.95	2.30	3.17	3.20	3.13	5.89	1.30	2.44	**33.64**
1884	4.45	5.62	4.87	3.29	2.43	1.53	3.83	3.11	0.89	2.48	2.85	**6.21**	41.56
1885	4.80	3.35	1.00	3.14	2.60	2.73	6.35	**10.27**	2.18	5.16	4.63	2.50	48.71
1886	5.28	6.08	2.58	3.83	3.18	1.97	5.45	2.43	4.31	2.29	4.67	3.76	45.83
1887	5.84	6.37	4.46	2.52	0.20	6.00	4.52	7.65	2.12	2.99	2.78	4.80	50.25
1888	4.22	4.07	3.03	2.10	4.50	1.12	2.98	3.84	8.55	5.23	5.22	5.43	50.29
1889	4.97	1.34	**1.64**	3.47	3.00	3.69	9.33	4.70	3.72	5.10	8.29	2.41	51.66
1890	2.25	3.48	6.18	2.92	5.08	3.37	3.83	4.12	4.55	5.86	0.80	3.18	45.62
1891	**8.48**	4.27	4.75	3.35	2.00	1.92	5.41	3.52	3.28	3.57	2.93	4.99	48.47
1892	4.77	1.68	2.16	1.01	5.59	2.31	2.84	6.69	2.57	1.39	5.81	1.43	38.25
1893	3.20	4.27	5.11	3.61	7.18	2.71	2.18	4.37	2.08	5.35	2.59	3.67	46.32
1894	1.72	3.12	1.88	2.23	6.14	0.48	1.36	2.25	5.80	5.94	5.13	4.12	40.17
1895	4.83	1.42	2.90	4.38	2.13	2.20	4.54	6.92	2.34	4.52	6.01	3.18	45.37
1896	1.32	7.10	4.86	**0.73**	2.17	4.83	2.78	3.82	5.96	3.42	2.74	1.02	40.75
1897	3.50	3.14	2.98	2.21	5.43	4.24	**15.14**	3.57	1.65	0.60	5.85	5.28	53.59
1898	3.31	4.26	2.01	3.19	5.63	1.80	4.17	7.20	2.14	5.51	7.91	2.09	49.22
1899	3.35	2.53	5.92	2.74	2.16	2.52	4.83	0.90	3.53	2.20	2.68	1.42	34.78
1900	3.60	**8.28**	6.29	1.53	4.26	3.66	3.93	3.13	1.98	3.03	4.81	2.79	47.29
1901	1.39	**0.50**	6.83	**11.17**	7.23	0.69	3.24	5.53	4.64	3.74	2.06	9.34	56.36
1902	2.22	3.02	6.02	3.95	2.04	3.94	7.03	4.70	6.08	6.30	**0.74**	6.65	52.69

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1903	3.14	4.50	6.42	2.90	**0.25**	**10.81**	5.63	7.53	4.48	3.70	2.42	3.34	55.12
1904	3.24	2.31	3.20	5.70	2.86	2.45	3.51	5.49	6.93	2.78	1.32	2.28	42.07
1905	3.46	1.33	3.36	2.43	1.21	4.63	3.62	6.40	4.40	2.57	2.10	3.94	39.45
1906	2.25	1.67	4.53	4.76	4.21	2.11	6.32	2.05	3.20	6.28	2.52	2.17	42.07
1907	4.53	1.92	1.07	2.66	3.77	4.10	1.73	1.30	**10.77**	6.33	5.63	5.45	49.26
1908	3.47	5.33	3.09	1.97	7.11	1.76	5.05	5.41	1.63	1.62	1.00	3.65	41.09
1909	3.23	5.24	4.20	7.59	2.56	3.15	1.63	3.90	3.72	1.85	2.15	3.20	42.42
1910	6.28	3.62	1.16	4.12	2.77	4.07	2.55	2.49	3.34	0.81	4.78	1.69	37.68
1911	2.80	2.39	3.94	3.03	1.79	2.52	2.68	6.38	2.39	10.02	4.41	3.19	45.54
1912	1.50	3.21	6.76	3.99	5.17	0.57	2.26	3.15	2.09	1.78	4.09	4.59	39.16
1913	2.84	2.06	5.58	4.72	5.13	1.24	1.72	3.91	3.90	**9.67**	2.70	3.66	47.13
1914	3.09	2.21	3.88	3.93	3.13	2.10	4.56	1.93	0.33	3.45	3.01	3.92	35.54
1915	6.89	4.22	0.17	1.36	2.57	4.06	4.15	8.92	1.68	3.20	2.14	5.60	44.96
1916	**1.00**	5.23	2.50	2.83	3.34	4.42	4.09	4.64	4.11	1.67	3.19	2.90	39.92
1917	3.60	1.85	4.15	2.87	4.02	4.24	4.34	5.67	1.36	7.72	2.49	1.30	43.61
1918	3.49	2.91	2.18	4.24	2.50	3.83	3.41	2.37	5.60	0.85	2.69	3.95	38.02
1919	2.21	3.49	5.07	2.94	7.62	1.14	3.47	3.60	4.85	3.19	4.72	2.15	44.45
1920	2.55	3.85	3.08	5.88	3.70	7.34	5.29	3.11	9.12	0.80	6.05	6.18	**56.95**
1921	2.29	2.71	3.14	3.71	2.74	2.11	5.55	1.23	4.06	1.39	4.97	2.62	36.52
1922	1.61	1.77	6.15	1.84	5.27	6.48	5.24	5.70	1.93	2.56	1.10	3.96	43.61
1923	7.23	1.72	2.97	4.62	2.60	4.05	4.18	3.13	2.17	6.72	3.87	5.10	48.36
1924	5.06	2.90	1.30	7.56	4.50	2.18	**0.66**	4.75	5.12	**0.18**	2.20	1.87	38.28
1925	3.75	3.59	3.99	2.10	2.56	4.56	7.50	1.25	2.76	4.20	2.71	2.93	41.90
1926	2.47	3.64	3.10	2.85	2.40	1.62	3.39	4.37	2.47	4.36	7.28	2.76	40.71
1927	2.29	2.68	1.60	2.31	6.01	2.20	5.22	5.03	1.78	6.19	7.04	5.00	47.35
1928	2.31	4.16	2.64	4.23	3.17	4.89	5.77	5.13	4.48	1.33	2.03	0.81	40.95
1929	4.41	4.32	3.21	7.32	4.56	1.70	1.16	2.59	1.96	4.99	2.62	3.73	42.57
1930	2.39	1.95	4.23	1.97	4.29	4.84	1.80	2.91	1.61	2.63	3.97	1.52	34.11
1931	3.12	1.49	4.22	3.06	5.67	4.34	2.58	4.26	1.30	1.94	1.05	2.73	35.76
1932	4.63	1.64	4.75	1.87	2.24	3.07	3.93	6.91	4.04	6.59	8.30	1.78	49.75
Means*	3.44	3.34	3.79	3.37	3.64	3.33	4.04	4.38	3.51	3.78	3.69	3.32	43.63
Normal†	3.52	3.46	3.60	3.37	3.55	3.11	4.31	4.30	3.67	3.67	3.67	3.61	43.84

*Means for 65 Years.

†1878–1927; 50-year period used by U. S. Government as normal period.

TABLE 3.— RAINFALL AT RESERVOIR NO. 1, WEST HARTFORD. COMPARISON OF THREE DRY PERIODS; RAINFALL FOR CALENDAR YEARS.

Year.	Rainfall.		
	Inches.	Percentage of	
		U. S. Normal Period.	Average Years Records.
1879	34.11	77.8	78.2
1880	36.88	84.1	84.5
1881	36.91	84.2	84.6
1882	37.04	84.5	84.9
1883	33.64	76.7	77.1
5 Year Average.	35.72	81.5	81.9
Years Record	43.63	99.5	100.0
Normal.	43.84	100.0	100.5
1908	41.09	93.7	94.2
1909	42.42	96.8	97.2
1910	37.68	85.9	86.4
1911	45.54	103.9	104.4
1912	39.16	89.3	89.8
5 Year Average.	41.18	93.9	94.4
Years Record	43.63	99.5	100.0
Normal.	43.84	100.0	100.5
1928	40.95	93.4	93.9
1929	42.57	97.1	97.6
1930	34.11	77.8	78.2
1931	35.76	81.6	82.0
1932	49.75	113.5	114.0
5 Year Average.	40.63	92.7	93.1
Years Record	43.63	99.5	100.0
Normal.	43.84	100.0	100.5

TABLE 4.— RAINFALL AT AMHERST, MASS., COMPARISON OF THREE DRY PERIODS; RAINFALL FOR CALENDAR YEARS.

Year.	Rainfall.		
	Inches.	Percentage of	
		U. S. Normal Period.	Average Years Records.
1879	45.99	105.2	105.0
1880	35.80	81.9	81.7
1881	42.12	96.4	96.1
1882	43.54	99.6	99.4
1883	38.87	88.9	88.7
5 Year Average.	42.45	97.1	96.9
Years Record	43.82	100.3	100.0
Normal.	43.70	100.0	99.7
1908	30.68	70.2	70.0
1909	39.13	89.5	89.3
1910	36.11	82.6	82.4
1911	44.21	101.2	100.9
1912	38.56	88.2	88.0
5 Year Average.	40.96	93.7	93.5
Years Record	43.82	100.3	100.0
Normal.	43.70	100.0	99.7
1928	41.97	96.0	95.8
1929	40.96	93.7	93.5
1930	32.84	75.1	74.9
1931	45.18	103.4	103.1
1932	39.42	90.3	90.0
5 Year Average.	40.07	91.7	91.4
Years Record	43.82	100.3	100.0
Normal.	43.70	100.0	99.7

Years of Record at Amherst — 1836–1931 = 96 years.

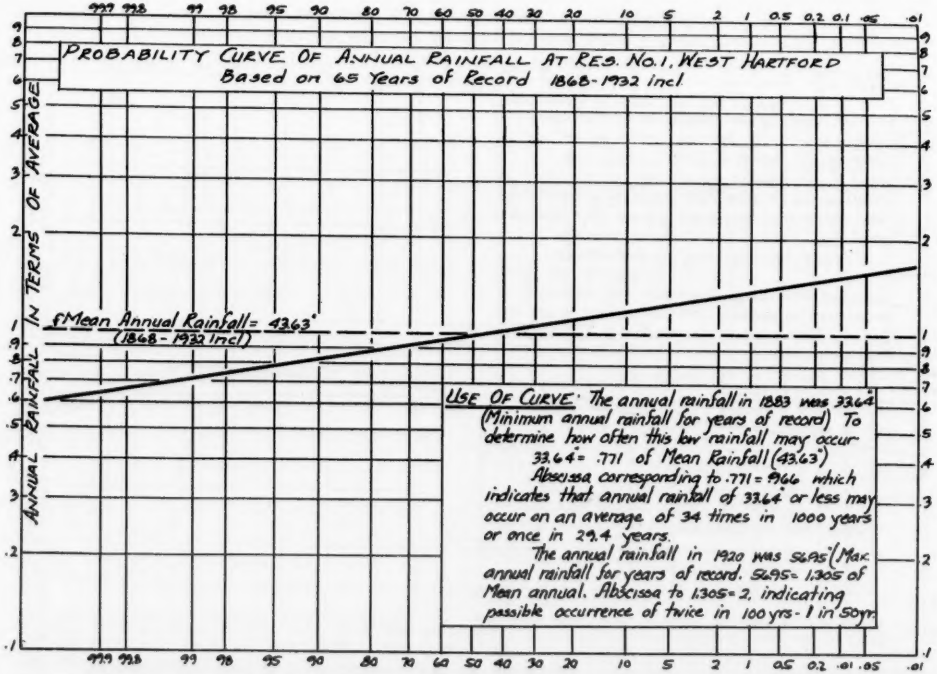

PROBABILITY CURVE OF ANNUAL RAINFALL AT RES. NO. 1, WEST HARTFORD
Based on 65 Years of Record 1868-1932 Incl
ANNUAL RAINFALL IN TERMS OF AVERAGE
Mean Annual Rainfall = 43.63"
(1868 - 1932 Incl)
USE OF CURVE: The annual rainfall in 1883 was 33.64" (Minimum annual rainfall for years of record) To determine how often this low rainfall may occur
33.64" = .771 of Mean Rainfall (43.63")
Abscissa corresponding to .771 = 9.66 which indicates that annual rainfall of 33.64" or less may occur on an average of 34 times in 1000 years or once in 29.4 years.
The annual rainfall in 1920 was 56.95" (Max. annual rainfall for years of record. 56.95 = 1.305 of Mean annual. Abscissa to 1.305 = 2, indicating possible occurrence of twice in 100 yrs - 1 in 50 yr.

FIG. 4.— PROBABILITY CURVE OF ANNUAL RAINFALL AT RESERVOIR NO. 1, WEST HARTFORD, BASED ON 65 YEARS OF RECORD 1868–1932.

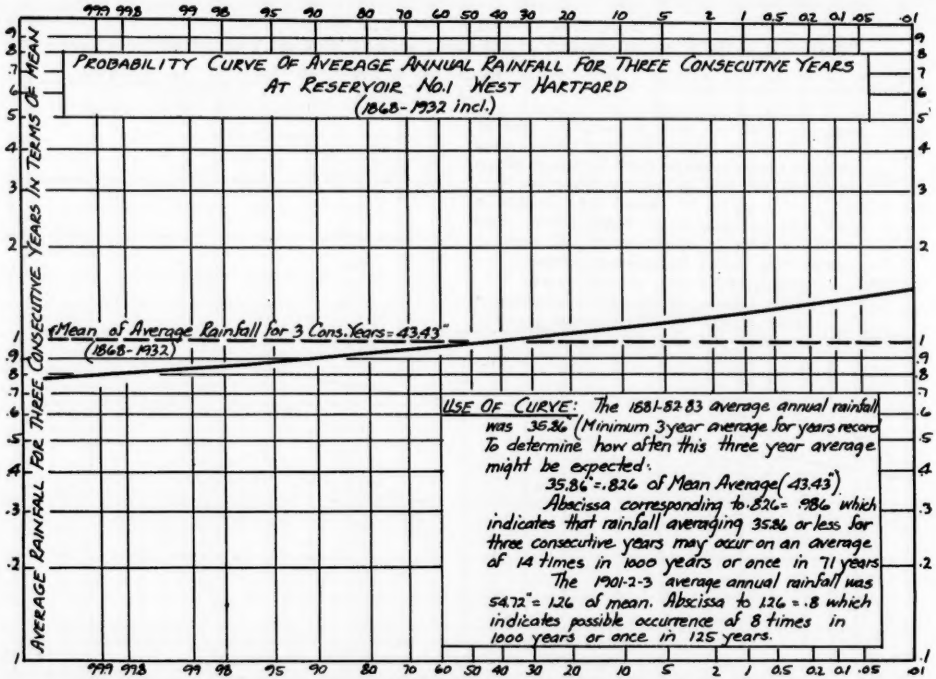

PROBABILITY CURVE OF AVERAGE ANNUAL RAINFALL FOR THREE CONSECUTIVE YEARS
AT RESERVOIR NO.1 WEST HARTFORD
(1868-1932 incl.)
AVERAGE RAINFALL FOR THREE CONSECUTIVE YEARS IN TERMS OF MEAN
Mean of Average Rainfall for 3 Cons. Years = 43.43"
(1868-1932)
USE OF CURVE: The 1881-82-83 average annual rainfall was 35.86" (Minimum 3-year average for years record.
To determine how often this three year average might be expected:
35.86" = .826 of Mean Average (43.43").
Abscissa corresponding to .826 = .986 which indicates that rainfall averaging 35.86 or less for three consecutive years may occur on an average of 14 times in 1000 years or once in 71 years.
The 1901-2-3 average annual rainfall was 54.72" = 1.26 of mean. Abscissa to 1.26 = .8 which indicates possible occurrence of 8 times in 1000 years or once in 125 years.

FIG. 5.— PROBABILITY CURVE OF AVERAGE ANNUAL RAINFALL FOR THREE CONSECUTIVE YEARS AT RESERVOIR NO. 1, WEST HARTFORD (1868–1932 incl.).

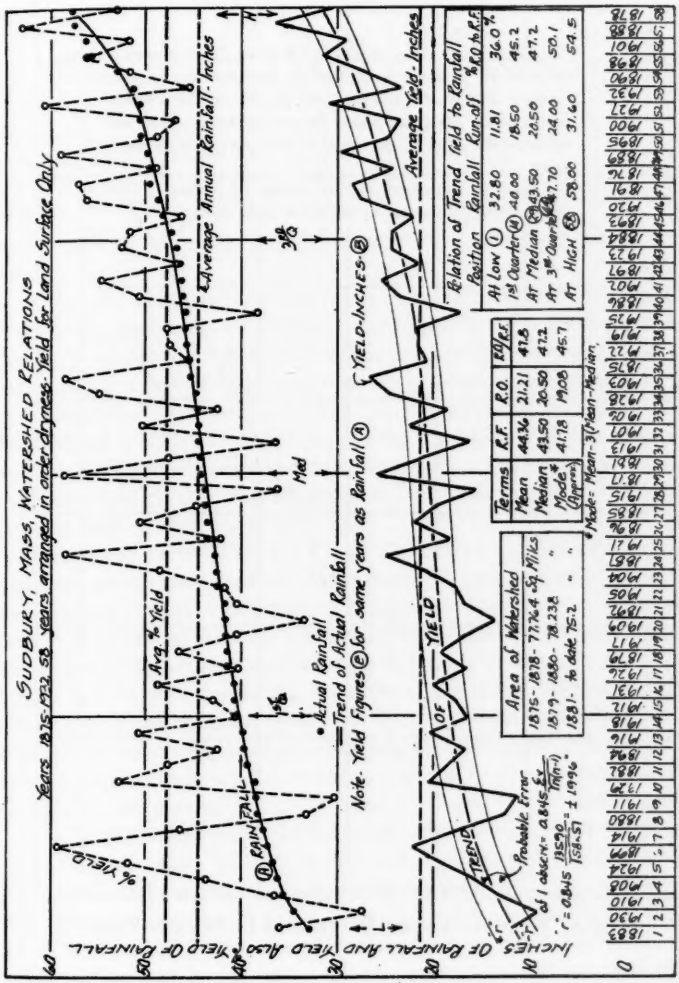

SUDBURY, MASS. WATERSHED RELATIONS
Years 1875-1932, 58 years arranged in order dryness. Yield for Land Surface Only.
Avg. % Yield
Average Annual Rainfall - Inches
Actual Rainfall
Trend of Actual Rainfall
Note. Yield figures (2) for same years as Rainfall (1)
YIELD-INCHES-(2)
Average Yield - Inches
Relation of Trend Yield to Rainfall
Area of Watershed
1875-1878 - 77.744 Sq. Miles
1879-1880 - 78.238 " "
1881- to date 75.2 " "
Terms | R.F. | R.O. | R/Rf
Mean | 44.36 | 21.21 | 47.8
Median | 43.50 | 20.50 | 47.2
Mode* (Approx.) | 41.78 | 19.08 | 45.7
Mode = Mean - 3(Mean - Median).
At Low (1) 32.80 11.81 36.0%
1st Quarter (14) 40.00 18.50 46.2
At Median (29) 43.50 20.50 47.2
At 3rd Quarter (44) 47.70 24.00 50.1
At High (58) 58.00 31.60 54.5
INCHES OF RAINFALL AND YIELD ALSO
% YIELD
YIELD OF RAINFALL
Probable Error of 1 observ. = 0.845 √(1/(n-1))
= 0.845 √(1/57) = ± 0.1996

FIG. 6.— SUDBURY, MASS. WATERSHED RELATIONS.

Years 1875–1932, 58 Years Arranged in Order of Dryness; Yield for Land Surface Only.

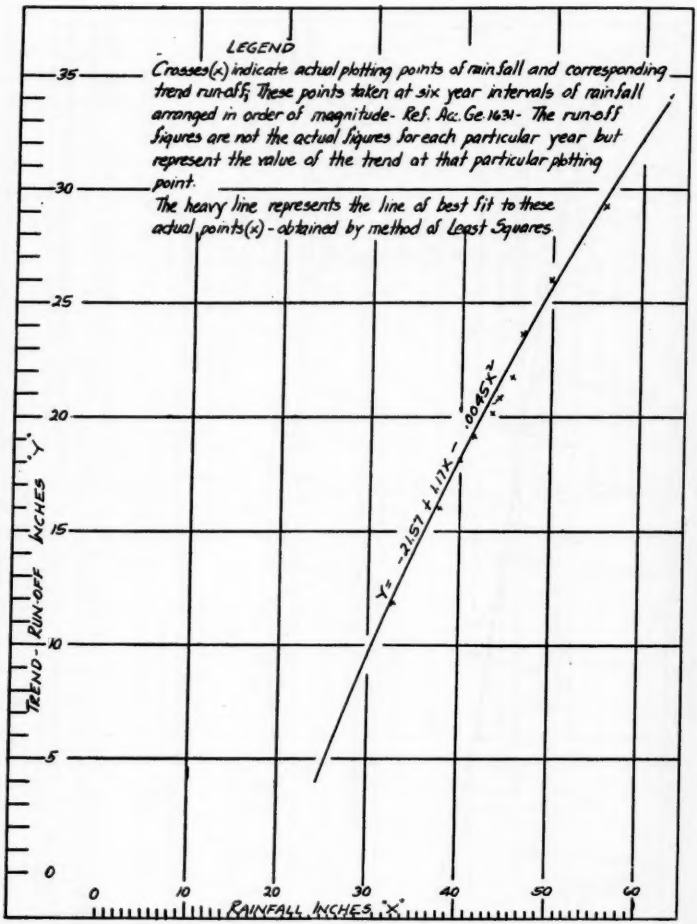

LEGEND
Crosses(x) indicate actual plotting points of rainfall and corresponding trend run-off; These points taken at six year intervals of rainfall arranged in order of magnitude- Ref. Acc. Ge. 1631- The run-off figures are not the actual figures for each particular year but represent the value of the trend at that particular plotting point.
The heavy line represents the line of best fit to these actual points(x) - obtained by method of Least Squares.
Y= -2.157 + 1.17X - .0045X²
TREND - RUN-OFF INCHES "Y"
RAINFALL INCHES "X"
0
5
10
15
20
25
30
35
40
50
60

FIG. 7.— SUDBURY RIVER WATERSHED, RELATION OF RAINFALL TO TREND YIELD.

amount of precipitation which are given at the bottom of Table 6, as well as the relationship of the amount of rainfall in these periods to the average of the years of record at West Hartford (Fig. 3 and Tables 19–21).

TABLE 5.— RAINFALL WEST HARTFORD.

Calendar Period.	Date.	Average Annual Inches.	Per cent. of 65-Year Average.	Frequency.	
				Times per 100 Years.	Once in Number of Years.
Lowest year.....	1883	33.64	77.1	3.4	29
Two lowest years....	1930–31	34.94	80.3	1.2	83
Three lowest years...	1881–83	35.86	82.2	1.4	71
Five lowest years....	1879–83	35.72	82.0	0.4	250

Although, as stated, the matter of relation of run-off to rainfall will not be given particular attention in this discussion, it seems pertinent to refer to it somewhat briefly hereafter, for the purpose of holding this relationship in mind while considering the principal topic. Figure 6, showing the relationship of rainfall to yield on the Sudbury watershed (Boston Metropolitan District Water Supply) over a period of 58 years, is offered merely as a suggested mode of attack on this complex problem. It is to be noted that yield on this diagram refers to land surface and does not include the water surface of the original table.

The run-off curve "Trend of Yield" in Figure 6 was not mathematically developed, as the nature of the data (samples) seemed not to warrant the expenditure of time; it was drawn in by eye but is believed to be sufficiently exact for the purpose in hand. Using "Peters" formula, the probable variation (error) of individual run-off records from this mean is found to be about 2 in. above or below this trend line, and their limits are shown as dotted lines on the diagram (lower curve). The variations from this curve probably are due mostly to chance happenings of weather, exclusive of rain, other natural and local conditions being common to all years except possibly slight differences due to change in vegetation cover. On this diagram are given, in tabular form, values for the extremes, the quarters and the median, also, in another table, the values of mean, median and mode. Values for both rainfall and run-off are here given together with their interrelationships. The principal lesson to be drawn from this diagram is the relationship between rainfall and run-off summarized in the table to the right, showing differences in the ratio valuations of run-off to rainfall varying from 36 per cent. to 54.5 per cent. on the basis of rainfall amount. The curve shown in Figure 7 indicates this general relationship mathematically. The general tendency of relationship between rainfall and run-off shown by the curve (Fig. 6) seems reasonable and in accord with fact; *i.e.*, the smaller the rainfall, the less the ratio of run-off to rainfall, or, *pari passu*, the greater

TABLE 6.— NEPAUG RIVER WATERSHED MINIMUM RAINFALL FOR CONSECUTIVE MONTHS WITH SAME PERIOD YIELD.
(Period of Record — April 1912–December 1932.)

No. of Cons. Months.	DATE OF PERIOD.	Yield Per Sq. Mile. M. G. D.	Yield Per Sq. Mile. C. F. S.	Total Rainfall Inches.	Total Yield Same Period Inches.	Percentage Yield of R. F. Col. 4 ÷ 3	Total Average Rainfall Same Period.	Total Average Yield Inches Same Period.	Percentage Total Yield ÷ Tot. Av. Yield Col. 4 ÷ 7.	Percentage Total Rainfall ÷ Tot. Av. R.F. Col. 3 ÷ 6.	Percentage Tot. Av. Yield ÷ Tot. Av. R.F. Col. 7 ÷ 6.
		1	2	3	4	5	6	7	8	9	10
1	March 1915	0.717	1.110	0.13	1.28	984.6	3.47	4.19	30.5	3.7	120.7
2	March–April 1915	0.863	1.335	2.18	3.02	138.5	7.19	7.97	37.9	30.3	110.8
3	Oct.–Dec. 1928	0.388	0.600	4.44	2.06	46.4	10.90	4.62	44.6	40.7	42.4
4	Mar.–June 1915	0.538	0.832	7.29	4.91	67.4	14.77	11.83	41.5	49.4	80.1
5	July 1931–Nov. 1931	0.138	0.214	10.56	1.22	11.5	19.14	5.14	23.7	55.2	26.8
6	July 1931–Dec. 1931	0.171	0.265	12.43	1.81	13.5	22.40	6.88	26.4	60.0	30.7
7	Aug. 1931–Feb. 1932	0.342	0.529	17.80	4.17	23.5	25.07	9.91	42.1	71.0	39.5
8	July 1931–Feb. 1932	0.332	0.513	20.43	4.53	22.6	28.75	10.70	43.2	71.1	37.2
9	Sept. 1931–May 1932	0.653	1.011	23.88	10.28	43.0	32.10	19.64	52.3	74.4	61.2
10	Aug. 1931–May 1932	0.603	0.933	27.36	10.55	38.6	36.30	20.45	51.6	75.4	56.3
11	July 1931–May 1932	0.572	0.885	29.99	11.01	36.8	39.98	21.24	51.8	75.0	53.1
12	July 1931–June 1932	0.558	0.864	33.55	11.72	34.9	43.52	22.53	52.0	77.1	51.8
15	Sept. 1930–Nov. 1931	0.621	0.961	44.19	16.33	37.0	54.78	26.07	62.6	80.7	47.6
18	July 1930–Dec. 1931	0.551	0.853	53.82	17.41	32.4	65.92	29.41	59.2	81.6	44.6
24	Jan. 1930–Dec. 1931	0.641	0.992	71.72	26.91	37.5	87.04	45.06	59.7	82.4	51.8
30	June 1929–Nov. 1931	0.587	0.908	89.94	30.81	34.3	109.72	51.49	59.8	82.0	46.9
36	June 1929–May 1932	0.644	0.997	109.37	40.60	37.2	130.56	67.59	60.1	83.8	51.8
48	Oct. 1928–Sept. 1932	0.733	1.135	154.24	61.56	39.9	174.08	90.12	68.5	88.5	51.7
60	Aug. 1921–July 1926	0.977	1.511	205.35	102.55	49.8	217.60	112.65	91.0	94.4	51.8

YEARS OF LEAST RAINFALL.

Years.	Average Inches.	Per cent. of Mean[1]	Period.
1	33.55	77.1	July 1931–June 1932
2	35.86	82.4	Jan. 1930–Dec. 1931
3	36.46	83.8	June 1929–May 1932
4	38.56	88.6	Oct. 1928–Sept. 1932
5	41.07	94.4	Aug. 1921–July 1926

[1]Average Rainfall for Years of Record — April 1912–December = 43.52 inches.
Average Run-off for Years of Record — April 1912–December 1932 = 22.53 inches.
Area of Watershed = 23.9 square miles — Area of Reservoir Watershed = 31.85 square miles.

TABLE 7.— NEPAUG RIVER WATERSHED MINIMUM YIELDS AND RAINFALLS FOR CONSECUTIVE MONTHS

TABLE 7.— NEPAUG RIVER WATERSHED MINIMUM YIELDS AND RAINFALLS FOR CONSECUTIVE MONTHS.
(Period of Record — April 1912–December 1932.)

No. of Cons. Months.	DATE OF LOW YIELD.	YIELD PER SQ. MILE		Total Yield Inches.	Total Rainfall[2] For Period.	Percentage Yield of R.F. (Col. 5 ÷ 6.)	Total Average[1] Yield for Period (Inches).	Total Average[3] Rainfall Same Period.	Percentage Total Yield ÷Tot. Av. Yield Col. 5 ÷ 8.	Percentage Tot. Rainfall ÷Tot. Av. R.F. Col. 6 ÷ 9.	Percentage Tot. Av. Yield ÷ Tot. Av. R.F. Col. 8 ÷ 9.
		M. G. D.	C. F. S.								
1	2	3	4	5	6	7	8	9	10	11	12
1	Sept. 1931	0.071	0.110	0.123	1.01	12.2	0.66	3.62	18.6	27.9	18.3
2	Sept.–Oct. 1931	0.074	0.115	0.261	3.20	8.2	1.81	7.42	14.4	43.2	24.4
3	Aug.–Oct. 1930	0.086	0.133	0.455	7.42	6.1	2.62	11.62	17.4	63.9	22.6
4	Aug.–Nov. 1931	0.109	0.168	0.762	7.93	9.6	4.35	15.46	17.5	51.3	28.1
5	July–Nov. 1931	0.138	0.214	1.218	10.56	11.5	5.14	19.14	23.7	55.2	26.8
6	July–Dec. 1931	0.171	0.265	1.813	13.43	13.5	6.88	22.40	26.4	60.0	30.7
7	July 1930–Jan. 1931	0.189	0.293	2.343	19.60	12.0	8.87	25.77	26.5	76.1	34.5
8	July 1930–Feb. 1931	0.207	0.320	2.892	21.38	13.5	10.70	28.75	27.0	74.2	37.2
9	June 1930–Feb. 1931	0.238	0.369	3.746	25.30	14.8	11.99	32.29	31.2	78.3	37.2
10	May 1930–Feb. 1931	0.283	0.438	4.952	29.28	16.9	14.56	36.33	34.0	80.6	40.0
11	April 1930–Feb. 1931	0.359	0.555	6.894	31.45	21.9	18.34	40.05	37.6	78.4	45.7
12	Mar. 1930–Feb. 1931	0.449	0.695	9.434	35.23	26.8	22.53	43.52	42.0	80.7	51.6
15	Aug. 1929–Oct. 1930	0.526	0.815	13.852	46.01	30.0	25.15	55.14	55.0	83.5	45.6
18	July 1929–Dec. 1930	0.481	0.744	15.190	53.20	28.6	29.41	65.92	51.6	80.9	44.7
24	April 1930–Mar. 1932	0.618	0.956	25.990	75.61	34.4	45.06	87.04	57.7	87.0	51.7
30	July 1929–Dec. 1931	0.582	0.901	30.626	90.03	34.1	51.94	109.44	59.0	82.5	47.4
36	July 1929–June 1932	0.643	0.995	40.556	110.15	36.7	67.59	130.56	60.0	84.5	51.6
42	May 1929–Oct. 1932	0.644	0.997	47.460	137.75	34.4	74.86	153.44	63.3	89.6	48.8
48	Oct. 1928–Sept. 1932	0.733	1.135	61.670	154.24	40.0	90.12	174.08	68.5	88.5	51.7
60	Jan. 1928–Dec. 1932	0.888	1.374	93.358	207.30	45.1	112.65	217.60	82.7	95.5	47.2
72	June 1926–May 1932	0.968	1.498	122.118	252.38	48.4	135.18	261.12	90.3	96.9	51.8
84	April 1925–Mar. 1932	0.948	1.467	139.504	293.41	47.6	157.71	304.64	88.7	96.2	51.8
96	Oct. 1924–Sept. 1932	0.932	1.442	156.700	331.90	47.2	180.24	348.16	87.0	95.2	51.8
108	Aug. 1923–July 1932	0.960	1.485	181.587	375.59	48.4	202.77	391.68	89.5	95.8	51.8
120	Oct. 1922–Sept. 1932	0.972	1.504	204.326	420.64	48.6	225.30	435.20	90.8	96.7	51.8

[1]Average Monthly Run-off based on Years Record — April 1912–December 1932 inclusive.
[2]Total Rainfall for Same Period as Low Yield.
[3]Average Monthly Rainfall, based on Years Record — April 1912–December 1932 inclusive.

TABLE 8.— PERIODS OF MINIMUM RAINFALL AT CANTON AND WEST HARTFORD.
Consecutive Monthly Periods.

Lowest Period In Months.	CANTON, CONN.			WEST HARTFORD, CONN.		
	Period From	To	Average Annual Inches.	Percent of Years of Record.*	Period From	To.	Average Annual Inches.	Percent of Years of Record.†
12	July '59	June '60	27.08	55.5	July '79	June '90	30.41	70.0
24	July '59	June '61	35.85	73.4	Oct. '79	Sept. '81	34.25	79.0
36	June '59	May '62	37.69	77.2	Sept. '79	Aug. '82	33.98	78.0
48	Jan. '59	Dec. '62	40.88	83.8	Sept. '79	Aug. '83	34.71	80.0
60	Jan. '79	Dec. '83	41.98	86.0	Jan. '79	Dec. '83	35.72	82.0
*Yrs. Record	Jan. '59	Dec. '22	48.81	100.0	†Jan. '68	Dec. '32	43.63	100.0

TABLE. 9—RAINFALL AT AMHERST, MASS., BY DECADAL PERIODS.

DECADAL PERIOD.	Average Annual Rainfall.	Per cent. of Normal (43.70) 50 Years.	DECADAL PERIOD.	Average Annual Rainfall.	Per cent. of Normal (43.70,) 50 Years.
1843–1852	43.43	99.4	1893–1902	46.58	106.6
1853–1862	46.06	105.4	1903–1912	40.52	92.7
1863–1872	45.64	104.4	1913–1922	43.89	100.4
1873–1882	43.78	100.2	1923–1932	40.33	92.3
1883–1892	45.53	104.2			

TABLE 10.— NEPAUG DATA, 1912–1932.

Period.	Date.	Average Annual Amount Inches.	Per cent. of 21-Year Average.	Yield Inches.	Per cent. Collection for Period Stated.	Per cent. Collection to Average Collection.
Lowest 12 months	July '31–June '32	33.55	77	11.72	34.9	52.0
Lowest 24 months	1930–31	35.86	83	13.45	37.5	59.6
Lowest 36 months	June '29–May '32	36.46	84	13.53	37.2	60.1
Lowest 48 months	Oct. '28–Sept. '32	38.56	88	15.39	39.9	68.5
Lowest 60 months	Aug. '21–July '26	41.07	94	20.51	49.9	91.1
21 years	1912–32	43.52	100	22.53	51.8	100.0

TABLE 11.—PERIODS OF MINIMUM RAINFALL AT RESERVOIR NO. 1, WEST HARTFORD. CONSECUTIVE MONTHLY PERIODS COMPARED WITH CALENDAR YEARS. (Period of Record — January 1868–December 1932.)

No. of Months.	Consecutive Period Years.			Consecutive Calendar Years.		
	Period.	Amount Inches.	Per cent. of Av. Annual.*	Period.	Amount Inches.	Per cent. of Av. Annual.*
12	July 1879–June 1880	30.41	70.0	1883	33.64	77.0
24	Oct. 1879–Sept. 1881	34.25	79.0	1930–1931	34.94	80.0
36	Sept. 1879–Aug. 1882	33.98	78.0	1881–1883	35.86	82.0
48	Sept. 1879–Aug. 1883	34.71	80.0	1880–1883	36.12	83.0
60	Jan. 1879–Dec. 1883	35.72	82.0	1879–1883	35.72	82.0
120	Oct. 1874–Sept. 1884	38.06	87.0	1875–1884	38.74	89.0

*Average Annual Rainfall at Reservoir No. 1 = 43.63 inches — (1868–1932).

the retention or loss to evaporation and absorption for vegetative requirements. These curves are to be understood as relating to Sudbury River watershed conditions only and as previously stated are only suggestions of a method of attacking a complex problem.

Tables 6 and 7 contain both rainfall and run-off data from the 20-year record of the Nepaug watershed of the Hartford system; Table 6 is for minimum rainfall periods while Table 7 is for periods of minimum yield. It should be noted that, while the 24-month low rainfall is included in the period common to both records (Table 3), the low rainfall period at West Hartford occurred during an earlier term for which no run-off records are available from the Nepaug area. The rainfall for this station, however, may be approximated by reference to the 64-year Canton record* of 1859–1922 (Table 8) and to the decadal periods of the Amherst (Mass.) 1836–1832 record, to which reference again will be made also later in this paper (Table 9).

The inadequacy of the short period record is evident on comparison of the rainfall data in the tables, although the stations are comparatively close together.

Data of this kind usually refer to calendar years, but natural elements and their effects relating to rainfall and drought are no more confined to man-made periods than they are to man-made political boundaries, and in such a study as this, consecutive periods, regardless of calendar position, and watershed areas, must be considered as the units on which to base results which are dependable.

In Table 11 of minimum rainfalls at Reservoir No. 1, are given monthly and annual records of minimum rainfall, regardless of calendar years, and for consecutive periods regardless of calendar position. From these, it is shown that for consecutive periods, the annual rainfall for the 12-month period, July 1879–June 1880 of 30.41 in. was 3.23 in. less than that (33.64 in.) of the lowest calendar year (1883). Considering that this amount (30.41 in.) is a little less than 2 in. from the probable minimum of 28.48 in., likely for this station (see p. 375), the drop to that figure seems not at all unreasonable. It is to be noted also that rainfall in the actual three-year minimum period was 1.88 in. (5.25 per cent.) less than that of the three-year calendar period. This illustrates the futility of using calendar periods in matters of moment in water-supply study.

Severe as was the recent drought period (1929–31) and its effect on water supplies generally throughout the country, it was not excessively bothersome to the majority of water-supply works in the northeastern United States, nor were conditions nearly as critical for similar purposes as those during the low rainfall period of 50 years ago. The data in Table 12 give the relative rainfall amounts for the periods of record at West Hartford, Nepaug and East Branch areas for comparison. These records

*Not considered particularly reliable in later years.
Station about 1 mile east of "Nepaug."

show that, so far as rainfall was concerned, the period 1879–83 was quite the lowest for the West Hartford station.

Conditions for these same periods on the Sudbury River (Mass.) and Croton (N. Y.) watersheds are analyzed later and are shown in tabular form in Tables 13–18 for both calendar and actual periods.

The lowest calendar 12-month rainfall year on the Croton (65-year record) watershed, was 1917, with a rainfall of 36.28 in. and a yield of 16.83 in. on land surface, equivalent to 46.4 per cent. of the average rainfall and 72.9 per cent. of the average run-off for the years of record (Table 17). The lowest yield year (calendar period) from this basin, was in 1880, with a rainfall of 37.62 in. and a yield of 12.39 in., equivalent to 32.9 per cent. of the rainfall and 53.1 per cent. of the average run-off for the years of record. The lowest (calendar) 12-month rainfall year on the Sudbury River watershed (58-year record) was 1883 with a rainfall of 32.78 and a yield of 11.81 in. on land surface, equivalent to 36.0 per cent. of the rainfall and 55.7 per cent. of the average run-off for the years of record (Table 14). The lowest yield year (calendar) from this basin was in 1930 with a rainfall of 34.40 in. and a yield of 9.46 in., equivalent to 27.5 per cent. of the rainfall and 44.6 per cent. of the average run-off for the years of record.

From the Croton records (Table 16), it is evident that the rainfall for the period 1928–32 was least with an average of 44.32 in. per year. The average yield for the period, however, was 21.56 in., or 92.3 per cent. of the average run-off for the years of record, while for the period 1879–83, the average annual rainfall was 1.59 in. greater. The yield was only 17.19 in., equivalent to 37.4 per cent. of the rainfall and 73.6 per cent. of the average run-off. In other words, comparing the period 1879–83 with that of 1928–32, the rainfall was 3.6 per cent. more and the run-off 20.5 per cent. less. For the second dry period of the half century 1879–1932, that for 1908–12, while having by a little the greatest rainfall, its run-off was about midway between the other two. It appears, therefore, that while the rainfall in each period was about the same, the dryest period yet experienced in this locality was probably that of 1878–83, so far as water supply was concerned.

On the Sudbury River watershed of the Boston Metropolitan District, Tables 13 and 15, the 5-year period 1908–12 undoubtedly was that of lowest yield during the past half century. However, as the interval 1879–1883 at West Hartford (Table 20) and Canton 1859–62 (Table 8) had the lowest average rainfall for the 50 years of record; also because of closer proximity to the Croton watersheds of the New York water supply, with their lowest yield at this time (Tables 16 and 18) and in addition to this, the easterly (*i.e.*, blowing from the east) winds, it seems probable that the interval 1879–83 was the lowest yield period experienced in this locality (Central Connecticut) during the years of record, although probably the year 1859–60 may have had somewhat less rainfall (see Canton Table 8).

Referring again to this matter of low rainfall because of its importance

TABLE 12.— DEFICIENCY OF RAINFALL FOR 48 MONTH PERIODS AT WEST HARTFORD RESERVOIR NO. 1, NEPAUG, EAST BRANCH. (Rainfall in Inches.)

Period.	Months.	West Hartford Res. No. 1. Rainfall.	West Hartford Res. No. 1. Average Years Record.	West Hartford Res. No. 1. 50 Years Average 1878–1927	Nepaug. Rainfall.	Nepaug. Average Years Record.	East Branch. Rainfall.	East Branch. Average Years Record.
June–Dec. 1929	7	18.75	..	..	21.09	..	20.96	..
Jan.–Dec. 1930	12	34.11	..	..	34.89	..	34.63	..
Jan.–Dec. 1931	12	35.76	43.63	43.48	36.83	43.52	40.66	43.48
Jan.–Dec. 1932	12	49.75	..	..	49.85	..	48.69	..
Jan.–May 1933	5	15.05	..	..	17.80	..	16.92	..
June 1929–May 1933	48	153.42	174.52	175.36	160.44	174.08	161.86	173.92
Observed Rainfall.			153.42	153.42		160.44		161.86
Deficiency for 48 Months.			21.10	21.94		13.64		12.06

West Hartford Reservoir No. 1.

Period.	Months.	June 1879–May 1883. Rainfall.	June 1879–May 1883. Average Years Record.	June 1879–May 1883. 50 Year Average 1878–1927.	June 1908–May 1912. Rainfall.	June 1908–May 1912. Average Years Record.	June 1908–May 1912. 50 Years Average 1878–1927.	June 1929–May 1933. Rainfall.	June 1929–May 1933. Average Years Record.	June 1929–May 1933. 50 Year Average 1878–1927.
June–Dec.	7	20.72	..	..	20.12	..	..	18.75	..	..
Jan. –Dec.	12	36.88	..	..	42.42	..	..	34.11	..	..
Jan. –Dec.	12	36.91	43.63	43.84	37.68	43.63	43.84	35.76	43.63	43.84
Jan. –Dec.	12	37.04	..	..	45.54	..	..	49.75	..	..
Jan. –May	5	12.21	..	..	20.63	..	..	15.05	..	..
Total Months.	48	143.76	174.52	175.36	166.39	174.52	175.36	153.42	174.52	175.36
Observed Rainfall			143.76	143.76		166.39	166.39		153.42	153.42
Deficiency for 48 Months.			30.76	31.60		8.13	8.95		21.10	21.94

Period.	Mos.	West Hartford Reservoir No. 1. Rainfall.	West Hartford Reservoir No. 6. Rainfall.	Hartford Weather Bureau. Rainfall.
June–Dec. 1929	7	18.75	18.23	19.25
Jan. –Dec. 1930	12	34.11	33.17	33.06
Jan. –Dec. 1931	12	35.76	34.99	36.14
Jan. –Dec. 1932	12	49.75	48.20	44.42
Jan. –May 1933	5	15.05	13.64	17.46
June 1929–May 1933	48	153.42	148.23	150.33

TABLE 13.— SUDBURY WATERSHED RAINFALL AND RUN-OFF DURING THREE DRY PERIODS.
Run-off Figures Are For Land Surface Only.
All Figures Are For Calendar Years.

Year.	Rainfall.			Run-off.	
	Inches.	Percentage of: U. S. Normal Period.	Percentage of: Average Years Record.	Inches.	Percentage of Years of Record.
1879	41.42	93.1	93.4	19.28	90.9
1880	38.18	85.8	86.1	12.66	59.7
1881	44.17	99.3	99.6	21.04	99.2
1882	39.40	88.6	88.8	18.73	88.3
1883	32.78	73.7	73.9	11.81	55.7
5 Yr. Av.	39.19	88.1	88.3	16.70	78,7
Yrs. Rec.	44.36	99.7	100.0	21.21	100.0
Normal.	44.48	100.0	100.3	21.24	100.1
1908	36.15	81.3	81.5	15.85	74.7
1909	41.75	93.9	94.1	13.89	65.5
1910	35.64	80.1	80.3	13.06	61.6
1911	38.38	86.3	86.5	11.59	54.6
1912	40.72	91.5	91.8	17.50	82.5
5 Yr. Av.	38.53	86.6	86.9	14.38	67.8
Yrs. Rec.	44.36	99.7	100.0	21.21	100.0
Normal.	44.48	100.0	100.3	21.24	100.1
1928	44.70	100.5	100.8	24.52	115.6
1929	38.62	86.8	87.1	20.41	96.2
1930	34.40	77.3	77.5	9.46	44.6
1931	40.83	91.8	92.0	19.89	93.8
1932	51.12	114.9	115.2	23.22	109.5
5 Yr. Av.	41.93	94.3	94.5	19.50	91.9
Yrs. Rec.	44.36	99.7	100.0	21.21	100.0
Normal.	44.48	100.0	100.3	21.24	100.1

Run-off — From Land Surface Only.
United States Normal Period — 1878–1927 — (50 years).
Sudbury Record — 1875–1932 inclusive — (58 years).

TABLE 14.— SUDBURY RIVER WATERSHED MINIMUM RAINFALL AND RUN-OFF STATISTICS. (CALENDAR YEARS.)
(Period of Record — 1875–1932.)

*Minimum Rainfall Periods, with Corresponding Periods of Run-off.**
(*Land Surface Only.*)

Years.	Period (Calendar Years.)	Rainfall.		Run-off.		Per cent. of Collection.
		Inches.	Per cent. of Average.	Inches.	Per cent. of Average.	
1	1883	32.78	73.9	11.81	55.7	36.0
2	1882–1883	36.09	81.4	15.27	72.0	42.3
3	1910–1912	38.24	86.2	14.05	66.2	36.7
4	1908–1911	37.98	85.6	13.60	64.1	35.8
5	1908–1912	38.53	86.9	14.38	67.8	37.3

Minimum Run-off Periods† with Corresponding Periods of Rainfall.

Years.	Period (Calendar Years.)	Run-off.		Rainfall.		Per cent. of Collection.
		Inches.	Per cent. of Average.	Inches.	Per cent. of Average.	
1	1930	9.46	44.6	34.40	77.5	27.5
2	1910–1911	12.33	58.1	37.01	83.4	33.3
3	1909–1911	12.85	60.6	38.59	87.0	33.3
4	1908–1911	13.60	64.1	37.98	85.6	35.8
5	1908–1912	14.38	67.8	38.53	86.9	37.3

*Average Annual Rainfall for Years of Record — (1875–1932) = 44.36 inches.
†Average Annual Run-off for Years of Record — (1875–1932) = 21.21 inches. (Land Surface Only.)

TABLE 15.— PERIODS OF MINIMUM RAINFALL AT SUDBURY, MASS.
Consecutive Monthly, With Corresponding Periods of Run-off.
(Period of Record — January 1875–December 1932.)

No. of Cons. Months.	RAINFALL.			RUN-OFF (SAME PERIOD).		
	Period.	Average An. Am't. Inches.	Per cent. of Average Annual.†	Average An. Am't. Inches.	Per cent of Average Annual.	Per cent. of Run-off to Rainfall
12	Oct. 1882–Sept. 1883	27.34	61.6	12.35	58.2	45.2
24	Mar. 1910–Feb. 1912	34.64	78.1	11.24	53.0	32.4
36	Mar. 1910–Feb. 1913	36.76	82.9	13.24	62.4	36.0
48	Mar. 1908–Feb. 1912	37.37	84.2	12.92	60.9	34.6
60	Mar. 1908–Feb. 1913	38.09	85.9	13.78	65.0	36.2

PERIODS OF MINIMUM RUN-OFF AT SUDBURY, MASS.
Consecutive Monthly With Corresponding Periods of Rainfall.

No. of Cons. Months.	RUN-OFF.			RAINFALL (SAME PERIOD).		
	Period.	Average An. Am't. Inches.	Per cent. of Average Annual.*	Average Annual Inches.	Per cent. of Average Annual.	Per cent. of Run-off to Rainfall
12	Feb. 1930–Jan. 1931	9.07	42.8	35.73	80.5	25.4
24	Oct. 1909–Sept. 1911	11.03	52.0	35.33	79.6	31.2
36	Sept. 1908–Aug. 1911	11.94	56.3	36.25	81.7	32.9
48	Mar. 1908–Feb. 1912	12.92	60.9	37.37	84.2	34.6
60	April 1908–Mar. 1913	13.69	64.5	38.48	86.7	35.6

†Average Annual Rainfall — (1875–1932) = 44.36 inches.
*Average Annual Run-off — (1875–1932) = 21.21 inches (Land Surface Only).

TABLE 16.— CROTON WATERSHED RAINFALL AND RUN-OFF DURING THREE DRY PERIODS.
Run-off Figures Are For Land Surface Only.
All Figures Are For Calendar Years.

Year.	RAINFALL.			RUN-OFF.	
	Inches.	Percentage of: U. S. Normal Period.	Percentage of: Average Years Record.	Inches.	Percentage of Years of Record.
1879	48.38	99.5	101.3	19.00	81.3
1880	37.62	77.4	78.8	12.39	53.0
1881	47.18	97.9	98.8	18.33	78.4
1882	53.32	109.7	111.6	23.35	99.9
1883	43.05	88.5	90.1	12.90	55.2
5 Yr. Av.	45.91	94.4	96.1	17.19	73.6
Yrs. Rec.	47.76	98.2	100.0	23.37	100.0
Normal.	48.62	100.0	101.8	23.77	101.7
1908	42.99	88.4	90.0	19.87	85.0
1909	51.54	106.0	107.9	19.68	84.2
1910	43.17	88.8	90.4	19.28	82.5
1911	48.06	98.8	100.6	19.68	84.2
1912	45.60	93.8	95.5	22.87	97.9
5 Yr. Av.	46.27	95.2	96.9	20.28	86.8
Yrs. Rec.	47.76	98.2	100.0	23.37	100.0
Normal.	48.62	100.0	101.8	23.77	101.7
1928	48.48	98.7	101.5	31.58	135.1
1929	44.06	89.6	92.3	22.53	96.4
1930	39.44	80.1	82.6	14.66	62.7
1931	43.39	88.2	90.9	20.36	87.1
1932	46.22	94.1	96.8	18.65	79.8
5 Yr. Av.	44.32	91.2	92.8	21.56	92.3
Yrs. Rec.	47.76	98.2	100.0	23.37	100.0
Normal.	43.62	100.0	101.8	23.77	101.7

United States Normal Period — 1878–1927.
Croton Record — 1868–1932 inclusive.

TABLE 17.— CROTON RESERVOIR WATERSHED, MINIMUM RAINFALL AND RUN-OFF STATISTICS. (Run-off — Land Surface Only.)
(Period of Record — 1868–1932.)

Minimum Rainfall Periods, with Corresponding Periods of Run-off.

Years.	Period Calendar Years.	Rainfall.		Run-off.		Per cent. of Collection.
		Inches.	Per cent. of Average.	Inches.	Per cent. of Average.	
1	1917	36.28	76.0	16.83	72.0	46.4
2	1917–1918	38.67	81.0	17.78	76.1	46.0
3	1916–1918	39.73	83.2	21.52	92.1	54.2
4	1872–1875	42.01	88.0	22.41	95.9	53.3
5	1872–1876	41.99	87.9	22.07	94.4	52.6

Minimum Run-off Periods, with Corresponding Periods of Rainfall.

Years.	Period Calendar Years.	Run-off.		Rainfall.		Per cent. of Collection.
		Inches.	Per cent. of Average.	Inches.	Per cent. of Average.	
1	1880	12.39	53.0	37.62	78.8	32.9
2	1880–1881	15.36	65.8	42.40	88.8	36.2
3	1879–1881	16.57	70.9	44.39	92.9	37.3
4	1880–1883	16.74	71.6	45.29	94.8	37.0
5	1879–1883	17.19	73.6	45.91	96.1	37.4

Average Annual Rainfall — (1868–1932) = 47.76 inches.
Average Annual Run-off — (1868–1932) = 23.37 inches (Land Surface Only.)

TABLE 18.— PERIODS OF MINIMUM RAINFALL AT CROTON, N. Y.
Consecutive Monthly, With Corresponding Periods of Run-off.
(Period of Record — January 1868–December 1932.)

No. of Cons. Months.	Rainfall.			Run-off (Same Period).		
	Period.	Average Annual Amount.	Per cent. Average Annual.*	Average Annual Amount.	Per cent. Average Annual.†	Percent R.O. +R.F.
12	Oct. 1916–Sept. 1917	33.27	69.7	17.68	75.7	53.1
24	Dec. 1916–Nov. 1918	38.31	80.2	17.76	76.0	46.4
36	Jan. 1916–Dec. 1918	39.73	83.2	21.52	92.1	54.2
48	Aug. 1871–July 1875	41.16	86.2	22.03	94.3	53.5
60	Dec. 1913–Nov. 1918	41.84	87.6	22.89	97.9	54.8

*Average Annual Rainfall — (1868–1932) = 47.76 inches.
†Average Annual Run-off — (1868–1932) = 23.37 inches.

TABLE 19.— MINIMUM RAINFALL AT RESERVOIR NO. 1 WEST HARTFORD.
Consecutive Months and Calendar Years.
(January 1868–1932 inclusive.)

Years of Cons. Months.	Date of Period.	Rainfall for Period.		Average Monthly Years of Record (Same Period).	Per cent. Period (Col. 2) Years of Record (Col. 2 ÷ 3).	Per cent. (Col. 1) of Average Annual Rainfall.*
		Total Rainfall Inches.	Average Monthly for Period.			
		1	2	3	4	5
1	June 1873	0.15	0.15	3.33	4.5	0.3
2	Mar.-April 1915	1.53	0.77	3.58	21.7	3.5
3	July-Sept. 1870	3.70	1.23	3.98	30.9	8.5
4	Oct. 1874–Jan. 1875	6.83	1.71	3.56	48.0	15.7
5	May 1870–Sept. 1870	9.03	1.81	3.78	47.9	20.7
6	Sept. 1879–Feb. 1880	12.96	2.16	3.51	61.5	29.7
7	Nov. 1904–May 1905	15.39	2.20	3.51	62.7	35.3
8	Oct. 1879–May 1880	16.82	2.10	3.55	59.2	38.6
9	Sept. 1879–May 1880	19.62	2.18	3.54	61.6	45.0
10	Sept. 1879–June 1880	20.35	2.04	3.52	58.0	46.6
11	Sept. 1874–July 1875	25.47	2.32	3.61	64.3	58.4
12	July 1879–June 1880	30.41	2.53	3.64	69.7	69.7
15	Oct. 1882–Dec. 1883	38.76	2.58	3.63	71.1	88.8
18	Jan. 1879–June 1880	47.34	2.63	3.59	73.3	108.5
24	Oct. 1879–Sept. 1881	68.49	2.85	3.64	78.5	157.0
30	June 1929–Nov. 1931	85.89	2.86	3.67	77.9	196.9
36	Sept. 1879–Aug. 1882	101.95	2.83	3.64	77.9	233.7
48	Sept. 1879–Aug. 1883	138.83	2.89	3.64	79.5	318.2
60	Jan. 1879–Dec. 1883	178.58	2.93	3.64	81.9	409.3
120	Oct. 1874–Sept. 1884	380.60	3.17	3.64	87.2	872.3

50 Year Normal (1878–1927) = 43.84
Average Annual Rainfall Reservoir No. 1 = 43.63 (1868–1932).

PERIOD YEARS OF LEAST RAINFALL AT WEST HARTFORD RESERVOIR NO. 1.

Average	1 Year	30.41	70% of Average*	July 1879–June 1880
	2 "	34.25	79% " "	Oct. 1879–Sept. 1881
	3 "	33.98	78% " "	Sept. 1879–Aug. 1882
	5 "	35.72	82% " "	Jan. 1879–Dec. 1883
	65 "	43.63	100% " "	Jan. 1868–Dec. 1932

*Average Annual Rainfall at Reservoir No. 1 = 43.63 inches — (1868–1932).

TABLE 20.— MINIMUM RAINFALL AT RESERVOIR No. 1 WEST HARTFORD.
Consecutive Months and Calendar Years. (January 1868–1932.)

Consecutive Period Years.

No. of Cons. Mos.	DATE OF PERIOD.	Average 12 Months Rainfall.	Per cent. of Average Rainfall.*
12	July 1879–June 1880	30.41	70
24	Oct. 1879–Sept. 1881	34.25	79
36	Sept. 1879–Aug. 1882	33.98	78
48	Sept. 1879–Aug. 1883	34.71	80
60	Jan. 1879–Dec. 1883	35.72	82
120	Oct. 1874–Sept. 1884	38.06	87

Consecutive Calendar Years.

No. of Years.	YEARS.	Average Yearly Rainfall.	Per cent. of Average Annual Rainfall.*
1	1883	33.64	77
2	1930–1931	34.94	80
3	1881–1883	35.86	82
4	1880–1883	36.12	83
5	1879–1883	35.72	82
10	1875–1884	38.74	89

50 Year Normal – (1878–1927) = 43.84 inches.
*Average Annual Rainfall at Reservoir No. 1 = 43.63 inches (1868–1932.)

TABLE 21.— MAXIMUM RAINFALL AT RESERVOIR NO. 1 WEST HARTFORD.
Consecutive Months and Calendar Years.
(January 1868–December 1932.)

No. of Cons. Months.	Date of Period.	RAINFALL FOR PERIOD.		Average Monthly Years of Record (Same Period).	Per cent. Period (Col. 2) of Yearsof Record (Col. 2 ÷3).	Per cent. (Col. 1) of Average* Annual Rainfall.
		Total Rainfall Inches.	Average Monthly Inches.			
		1	2	3	4	5
1	July 1897	15.14	15.14	4.04	374.8	34.7
2	June-July 1897	19.38	9.69	3.69	262.6	44.4
3	Mar.-May 1901	25.23	8.41	3.60	233.6	57.8
4	June-Sept. 1903	28.45	7.11	3.82	186.1	65.2
5	May–Sept. 1868	32.62	6.52	3.78	172.5	74.8
6	Oct. 1869–Mar. 1870	38.02	6.34	3.56	178.0	87.1
7	Oct. 1869–April 1870	42.26	6.40	3.53	171.1	96.9
8	Sept. 1869–April 1870	45.72	5.81	3.53	164.6	104.8
9	Sept. 1907–May 1908	49.15	5.46	3.54	154.2	112.7
10	Mar. 1901–Dec. 1901	54.47	5.45	3.69	147.7	124.8
11	Mar. 1901–Jan. 1902	56.69	5.15	3.66	140.7	129.9
12	Sept. 1907–Aug. 1908	61.37	5.11	3.64	140.7	140.7
15	July 1902–Sept. 1903	77.16	5.14	3.70	138.9	176.9
18	Mar. 1902–Aug. 1903	88.63	4.92	3.68	133.7	203.1
24	April 1868–Mar. 1870	116.33	4.85	3.64	133.3	266.6
30	Mar. 1901–Aug. 1903	148.34	4.94	3.66	135.0	340.0
36	Mar. 1901–Feb. 1904	167.83	4.66	3.64	128.2	384.7
48	Jan. 1900–Dec. 1903	211.46	4.41	3.64	121.2	484.7
60	Nov. 1899–Oct. 1904	254.03	4.23	3.64	116.2	582.2
120	Oct. 1894–Sept. 1904	486.05	4.05	3.64	111.4	1141.0

50 Year Normal — (1878–1927) = 43.84 inches.
*Average Annual Rainfall at Reservoir No. 1 = 43.63 inches — (1868–1932).

TABLE 22.— MAXIMUM RAINFALL AT RESERVOIR NO. 1 WEST HARTFORD.
Consecutive Months and Calendar Years. (January 1868–1932.)

Consecutive Period Years

No. of Cons. Mos.	DATE OF PERIOD.	Average 12 Months Rainfall.	Per cent. of Average Rainfall.*
12	Sept. 1907–Aug. 1908	61.37	141
24	April 1868–Mar. 1870	58.17	133
36	Mar. 1901–Feb. 1904	55.94	128
48	Jan. 1900–Dec. 1903	52.87	121
60	Nov. 1899–Oct. 1904	50.81	116
120	Oct. 1894–Sept. 1904	48.61	111

Consecutive Calendar Years.

No. of Years.	YEARS.	Average Yearly Rainfall.	Per cent. of Average Annual Rainfall.*
1	1920	56.95	131
2	1901–1902	54.52	125
3	1901–1903	54.72	125
4	1900–1903	52.87	121
5	1900–1904	50.71	116
10	1895–1904	47.72	109

50 Year Normal – (1878–1927) = 43.84 inches.
*Average Annual Rainfall at Reservoir No. 1 = 43.63 inches (1868–1932.)

TABLE 23.— RAINFALL PERCENTAGE TABLES ARRANGED IN GROUPS OF 10-YEAR INTERVALS.

Annual Precipitation Over Southern New England as Per cent. of Base.
As Shown at From 1 to 10 Stations — Base = 42.60 Inches.
For List of Stations Reference — "Monthly Weather Review," Vol. 51, No. 8, August 1923.

YEAR.	1750	1760	1770	1780	1790	1800	1810	1820	1830	
0	99.1	91.5	96.9	95.8	93.2	106.1	92.5	103.1	110.6	
1	124.6	77.0	106.3	85.7	103.8	93.2	111.7	99.5	114.1	
2	89.2	57.5	115.0	95.8	75.6	90.1	103.8	83.6	106.3	
3	122.1	95.1	76.5	116.7	83.1	101.6	125.4	125.8	93.0	
4	109.2	86.4	87.8	141.5	77.5	96.2	116.4	97.9	88.3	
5	90.4	77.0	96.9	146.7	110.3	84.0	107.3	86.2	85.2	
6	83.3	88.5	99.5	97.4	70.7	90.6	96.5	103.8	93.7	
7	96.9	99.5	83.3	86.4	92.5	106.3	101.9	123.7	82.9	
8	126.1	86.4	87.1	74.6	95.8	116.0	95.3	95.1	90.8	
9	114.8	74.6	100.9	94.6	83.1	104.7	85.2	107.5	92.3	
Total.	1055.7	833.5	950.2	1035.2	885.6	988.8	1036.0	1026.2	957.2	
Average.	105.6	83.4	95.0	103.5	88.6	98.9	103.6	102.6	95.7	
Order of Magnitude.	15	1	4	11	2	8	12	10	5	

YEAR.	1840	1850	1860	1870	1880	1890	1900	1910	1920	1930
0	100.5	123.7	96.2	105.9	89.7	119.7	106.6	83.1	112.4	77.0
1	104.0	102.3	102.3	112.4	104.0	109.4	118.1	93.2	88.0	94.6
2	97.2	101.6	109.2	106.8	98.1	89.0	107.0	92.7	103.3	100.7
3	108.7	120.0	122.1	107.0	87.3	107.7	104.5	94.4	95.3	
4	86.9	109.6	88.0	101.4	108.7	89.4	98.6	82.9	82.9	
5	97.4	105.6	103.8	104.5	97.9	97.7	89.9	106.1	93.4	
6	78.9	101.4	103.8	108.2	106.5	96.0	101.4	91.3	96.7	
7	107.5	112.9	114.3	104.0	112.7	116.7	101.6	88.5	109.6	
8	94.8	96.0	116.4	123.5	112.0	125.4	88.7	84.5	95.3	
9	88.0	117.1	118.3	100.2	119.5	95.5	91.5	101.9	91.8	
Total.	963.9	1090.2	1074.4	1073.9	1036.4	1046.5	1007.9	918.6	968.7	
Average.	96.4	109.0	107.4	107.4	103.6	104.7	100.8	91.9	96.9	
Order of Magnitude.	6	18	17	16	13	14	9	3	7	

Reference — *Eng. "Met. Magazine"— Vol. 63, February 1928. No. 745 by J. Glasspoole.

in this study, it has been noted that the greatest rainfall for twelve consecutive months at the West Hartford station (Tables 22 and 23) of 61.37 in., is 4.42 in. more than the amount during the maximum twelve months of the calendar year, although the minimum actual yield was only 30.41 in. Applying the "one-half" rule, the probable minimum annual rainfall to be expected would be 30.69 in., which is 0.28 in. greater than the recorded minimum and about 1.7 in. more than expectation, using the calendar maximum as a basis. From the probability curve (Fig. 4) it appears that the rainfall of 34.11 in. at the West Hartford station during 1930 may be expected there about once in 22 years. Actually, (Table 2) this amount, or less, has been observed at this station three times during the period of record, thus checking the diagram. As the extremes are approached, however, the probability of occurrence decreases very rapidly, and for the extreme calendar low of 28.47 in. for this station the expectancy is once in about 670 years.

While not always particularly mentioned in the text, Tables 19 to 22, 24 and 27 refer to rainfall conditions observed at West Hartford Station during 1868–1932. Table 23 accompanies Fig. 15 and refers to rainfall in Southern New England. Tables 25 and 26 refer to rainfall conditions observed at Nepaug Station during 1912–32.

In considering this method of portrayal, one must not lose sight of the principle on which it is founded; namely, on an infinite number of determinations, and, while the method leads to a mathematically correct solution* for that length of time, the present determinations are based on a comparatively small number of records. On this account, the results obtained must be recognized merely as indicating relative and not absolute frequency. In other words, experience shows that, while an annual rainfall as low as 28.47 in. is probable in the vicinity of the West Hartford station during an infinitely long period of years, this result may be expected on an average only about once in six or seven centuries. However, that "once" may be next year and not again for a thousand or more years, or it may be twice in 10 years and not again for several thousand years. The importance of this solution lies in the probable amount to be provided for and the relative frequency of its occurrence. The question is, what preparation is it reasonable to make for the eventuality of lowest probable rainfall for the given locality.

Allen Hazen† has stated that "the 95 per cent. dry year is used as a basis for municipal water supplies"; that is, five times in one hundred years or once in twenty, there might be a shortage of water. Hazen remarked however, that "for extra conservative estimates, the 98 per cent. year be used"; that is, provision for the drought that may be expected on an average, once in fifty years.

From the data that are given in this paper, from the actual experience

*i.e. if the samples are considered as "errors."

†*Am. Civil Engineers Handbook*, 5th Ed., pp. 1446–7.

of water-works men in this and similar localities during the drought period just passed through (1920–32), and, recalling reliable records of fifty years ago, it seems to the writer to be desirable that provision for at least fifty years in the future be considered as a reasonable minimum limit for water-supply development.

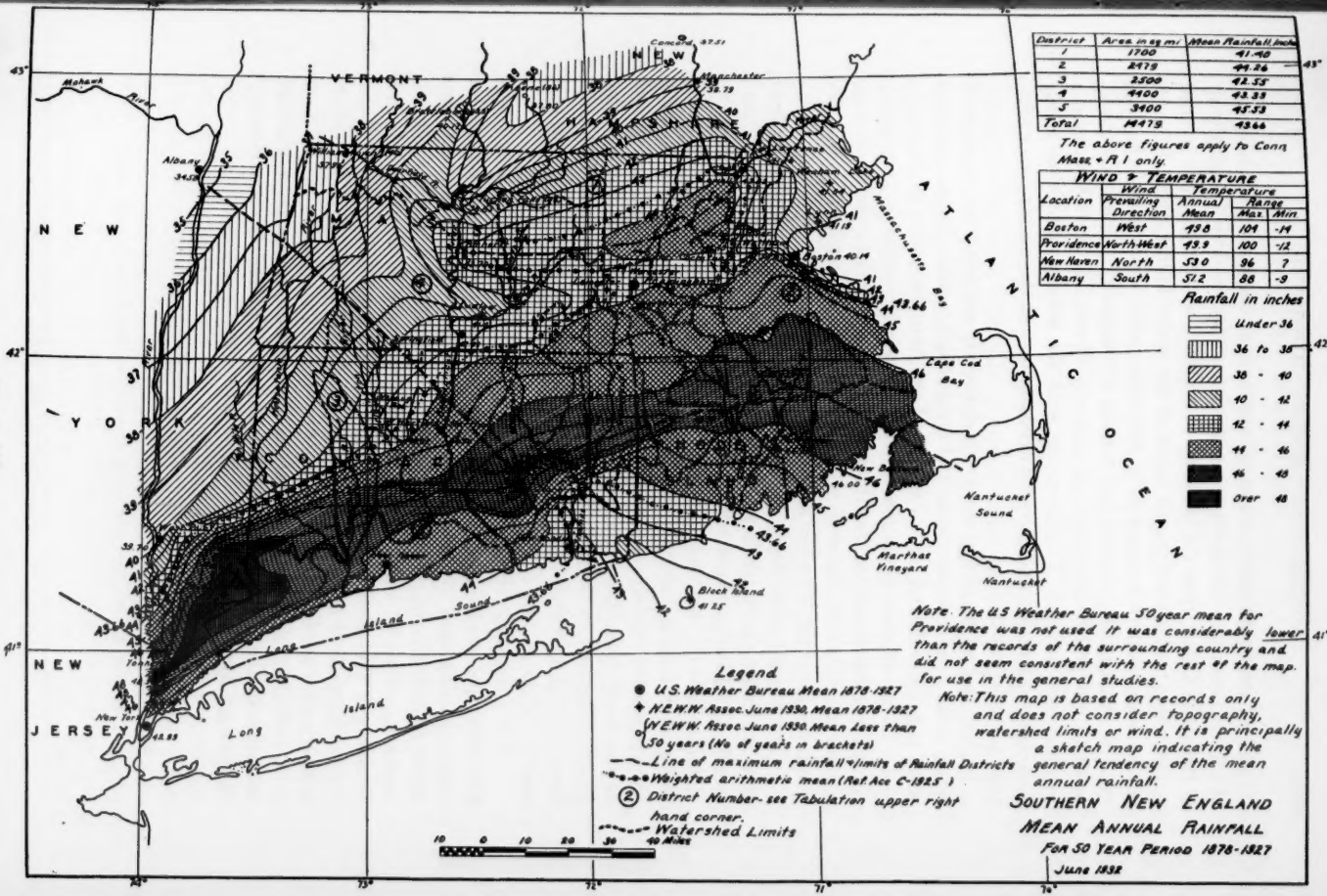
The relationship between rainfall and run-off seems to have too many complexities at the present time to attempt a general correlation formula, although it seems probable that by study of individual watersheds, it may be possible in time to arrive at some general laws that will be applicable. Obvious indication of the general relationship between rainfall and run-off is evident in the data plotted in Figures 6 and 7 (Sudbury River) showing the tendency of yield to increase with rainfall (see curve "Trend of per cent. yield") but not in the same ratio. Attention is called to the variation in run-off percentages with low and high rainfall amount; for example, relation of trend of rainfall and yield, Figure 6, table in lower right corner. It seems probable that some relationship such as this may be of value in the study of this phenomenon on individual watersheds..

General Meteorological Observations.

No attempt will be made to correlate any of the observed phenomena with sun spot or other periodicities. Many conservative meteorologists, while of an open mind, have not as yet subscribed fully to the theories on that subject which have been advanced by some of the ablest of scientists. Sir Gilbert T. Walker has aptly remarked, "There still are meteorologists and seismologists whose lack of familiarity with mathematical ideas enables them to ignore both Shuster's criterion and that which I have communicated, probably because the ordinary mode of statement appears too abstract." However, it goes almost without saying that all life movement and change on this planet which we call earth are fundamentally due to conditions emanating from that body which is the center of our Universe and which we call the sun. To this body, the earth is tied by the force of gravity which holds it to an elliptical orbit, over the full distance of which it travels in about 365 days, meantime rotating on its own axis from west to east once in about 24 hours, all of the time with that axis inclined 23½ degrees from the vertical. To these and other conditions are ascribed generally the change of the seasons and all of the phenomena which are generally comprised in the science of meteorology. The sun's heat and its distribution over the earth's surface is the cause of the winds and the weather.* All of this may be elementary "stuff," known to the schoolboy in his early days, but it is so important to the comprehension of even the rudiments of any study of atmospheric happening, that it is desirable to focus attention on the primary cause, even when considering what may appear to be minor parts of world weather. Barton† says: "Every transitory depression or anticyclone, and indeed every land or sea breeze, plays

*"The Weather," C. E. P. Brooks, p. 6. †*Quart. Jour. Roy. Met. Soc.*, 57 Jan. 1931.

PLATE III.


VERMONT
NEW YORK
NEW JERSEY
MASSACHUSETTS
ATLANTIC OCEAN
Concord 37.51
Manchester 39.79
Worcester 41.19
Boston 40.14
Providence 43.66
Albany 34.58
Cape Cod Bay
Nantucket Sound
Martha's Vineyard
Nantucket
Block Island 41.25
Long Island Sound
Long Island
New York 42.55
Mohawk River
Connecticut River
Hudson River
Housatonic River
Thames River
Taconic Range
Berkshire Hills
Green Mountains
Hoosac Mountains
Lenox 47.24
Pittsfield 42.90
Greenfield 37.90
Amherst 41.19
Northampton 43.66
Springfield 43.66
Hartford 43.66
New Haven 40.00
Waterbury 43.66
Litchfield 43.66
Danbury 43.66
Norwalk 43.66
Stamford 43.66
Bridgeport 43.66
Meriden 43.66
Middletown 43.66
New London 43.66
Norwich 43.66
Willimantic 43.66
Putnam 43.66
Thompson 43.66
Woodstock 43.66
Ashford 43.66
Windham 43.66
Scotland 43.66
Canterbury 43.66
Plainfield 43.66
Sterling 43.66
Voluntown 43.66
Stonington 43.66
Groton 43.66
Old Lyme 43.66
Old Saybrook 43.66
Essex 43.66
Clinton 43.66
Madison 43.66
Guilford 43.66
Branford 43.66
Wallingford 43.66
Cheshire 43.66
Southington 43.66
Bristol 43.66
Plainville 43.66
Farmington 43.66
Avon 43.66
Simsbury 43.66
Granby 43.66
Suffield 43.66
Enfield 43.66
Somers 43.66
Ellington 43.66
Vernon 43.66
Tolland 43.66
Coventry 43.66
Mansfield 43.66
Hebron 43.66
Andover 43.66
Bolton 43.66
Manchester 43.66
East Hartford 43.66
Glastonbury 43.66
Rocky Hill 43.66
Wethersfield 43.66
Newington 43.66
West Hartford 43.66
Windsor 43.66
Windsor Locks 43.66
East Windsor 43.66
South Windsor 43.66
Bloomfield 43.66
Berlin 43.66
New Britain 43.66
Plainville 43.66
Southington 43.66
Cheshire 43.66
Wallingford 43.66
Meriden 43.66
Middletown 43.66
Portland 43.66
Cromwell

its part in the determination and maintenance of the general circulation." While the oceans are the great reservoirs from which is drawn originally all of the water falling upon the land and to which all water ultimately returns, nevertheless, in its journeyings much of the water falling upon the earth comes from evaporation and reprecipitation many times over before the cycle of evaporation, rainfall and run-off is completed. Among the prominent causes which determine the amount of rainfall, are: Atmospheric pressure, rise and fall of temperature with the seasons, prevailing winds, geographical location and physical configuration of the country with reference to these winds.

East and south of the section under study are the wide expanses of water area of the Atlantic Ocean and Long Island Sound. To the north and west, parallel with and but a few miles back from the shore, are highlands and hills of sufficient elevation to effect physical changes in atmospheric conditions. In the winter months generally, the prevailing direction of the surface winds is from the west and northwest; in the summer months, the winds are generally from the south and southwest.

The general relationship of rain conditions in the South New England area are shown on Plate III which is offered as a sketch only and prepared merely as an indication of what has been experienced in this locality. No claim is made for that meteorological accuracy which would consider many other conditions in making up a synoptic chart. This chart is drawn solely from published rainfall data, with the lines of equal rainfall (isohyets) drawn as one would draw land surface contours and without regard to topography. Beside the contours, however, are shown the outlines of the principal drainage basins and sufficient of the topographical contours to indicate the general lay of the surface of the country.

The nearest meteorological station to the locality under study (Hartford Metropolitan District Water Supply System) where records of weather approximating that of this locality had been kept for a number of years under reliable control, is at the Massachusetts State Agricultural College at Amherst, about 45 miles to the north. Through the courtesy of C. I. Gunness of this station in furnishing the data, some tables are presented for the purpose of correlation with the rainfall and run-off data which are presented for the Hartford station.

Indication of condition of barometric pressure, temperature and wind is shown in the following summaries of records at the Amherst Station,* for comparative purposes:

*Agri. Exp. Sta. Bull. 270.

MEAN BAROMETRIC PRESSURE, 1889–1928.
(Reduced to Freezing and Sea Level.)

Month.	Inches.	Month.	Inches.
January	30.07	July	29.97
February	30.03	August	30.00
March	30.02	September	30.07
April	29.99	October	30.06
May	29.95	November	30.05
June	29.96	December	30.06

During the storm of November 4, 1927, the pressure dropped to 29.02 in., and during the drought period July–October, 1930 daily maxima for the several months respectively were 30.16, 30.36, 33.33 and 30.40 in., readings which are well above normal.

MEAN TEMPERATURE, 1889–1928.

Month.	Deg. F.	Month.	Deg. F.
January	20.8	July	70.6
February	23.5	August	68.4
March	34.2	September	61.6
April	45.8	October	50.4
May	56.8	November	38.6
June	65.4	December	37.3

The mean monthly temperature at Hartford is about 2.5° F. higher than that of Amherst.

TOTAL MEAN WIND MOVEMENT, 1889–1928.

Month.	Miles.	Per cent. Annual.	Month.	Miles.	Per cent. Annual.
January	5 068	9.5	July	3 435	6.4
February	4 833	9.1	August	3 099	5.8
March	5 738	10.8	September	3 252	6.1
April	5 436	10.2	October	4 023	7.5
May	4 540	8.5	November	4 564	8.5
June	3 584	6.7	December	4 726	8.9

Prevailing direction of wind is shown by the wind rose (Fig. 8), and it is of interest to note that about one third of the total wind direction is from a southerly direction, *i.e.*, moisture-bearing winds from the ocean, which is the prevailing direction during the months of July–September inclusive, when about 30 per cent. of the total rainfall is received in this locality. When the prevailing winds are from a southerly direction, the eastern portion of the country is wet, the precipitation decreasing with the shifting of the winds to the west. Warm, southerly winds coming over the ocean and from the south and Gulf of Mexico, are heavily laden with moisture. When these strike the land, condensation takes place on account of the colder temperature both of the surface of the ground with which the winds come in contact and also of the upper air into which the winds are diverted by the obstruction of the higher lands back from the coast.

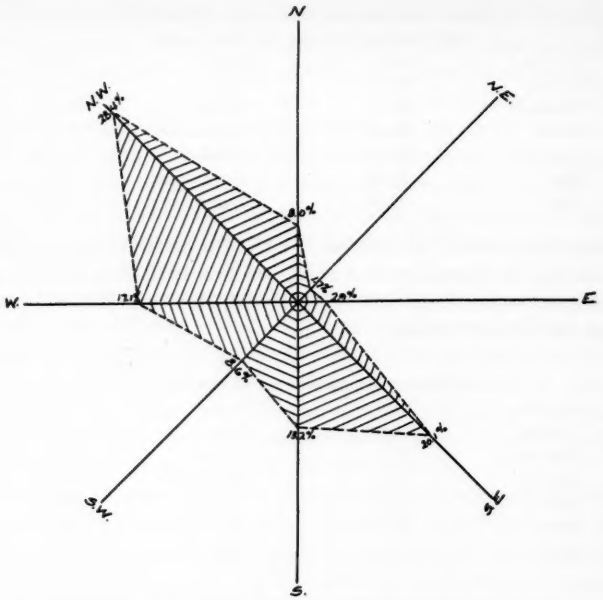


FIG. 8.— WIND ROSE, AMHERST, MASS.

This "Wind Rose" represents a Summary of Wind Direction for the Years 1929–32, with the Percentage of the Total Time (4 Years) for each Wind Direction, Plotted along the Respective Arms, 1 Per cent. Represented by Each Cross Line.

STATISTICAL CONSIDERATIONS.

In a study of rainfall and run-off, as well as other meteorological data, it is necessary to have some base or datum for reference. The terms "average," "mean" and "normal" are often loosely used as if they were of interchangeable meaning, thereby causing considerable confusion. It seems desirable, therefore, to discuss somewhat the meanings used in this study in reference to this matter.

The arithmetical average or mean which is the reference base most often used in discussing data of this kind, is the value obtained by dividing the sum of a number of individual observations (samples) by their number. While "mean" and "average" often are used as synonymous words, Sir Napier Shaw[1] recommends that the word "average" be used as the mean value of an irregular series of years or months, and H. R. Mill suggests "general rainfall" for expressing the mean of a number of values over a geographical area. When the mean values extend over a long series of years, the value tends toward a constant and then becomes the "normal"; that is a figure from which there is little deviation, no matter how long the series

[1] *Manual of Metorology*, 1, p. 256.

is extended. To find some common denominator, which, while not the ideal "normal" yet may be sufficiently near to be used as a base or datum with reference to which climatic fluctuation may be analyzed and examined, it is customary to use the mean of the observations in some definite period and call this the "normal." Sir Napier Shaw says: "the true idea of a normal for a period of years is that the mean value for every period of the same length of a very long series, would give the normal, and that necessarily would imply perfect recurrence at the completion of the period." Alfred J. Henry[1] defined a "true normal" as one which will not be materially altered however long the other values may be continued.

British rainfall correlations at present are based on the 35-year normal, which is the average of the records for the period 1881–1915. In connection with this matter, Hugh Robert Mill[2] states that, "30 years are quite sufficient to yield a satisfactory mean annual rainfall, if the limit of error may average two per cent. on either side of the true mean," with, of course, more extreme variations at particular periods in this range; he further remarks, "that in order to get substantially better results than the 30 years' average, it would be necessary to take a 50 years' average," but "on account of the difference which may exist between one period of 30 years and another, it is important to work with one and the same period for all stations, and to select a period the value of which is near the true mean of a much longer period." As to establishing steady values for the calendar months, deCarle S. Salter[3] stated that it is probable that "at least 100 years would be necessary" and that as such records are not generally available, one must be content with approximations to normal values derived from a lesser length of period.

It is evident from the length of the records which are available in this country, that conditions fulfilling Sir Napier Shaw's postulate have not yet arrived. In British rainfall studies, the 35-year period 1881–1915 was chosen, not because it was more reliable than any other, but because it was found by experience that a period of 35 years was sufficiently long to give practical stability[4] and was the most useful period at the time chosen. In the United States,[5] the 50-year period 1878–1927 has been computed by the United States Weather Bureau for government stations throughout the country, and, therefore, it is a most logical period to use in this country. While, theoretically, it is immaterial what period is used or the nearness with which that period approaches the "ideal," it is most important that one reference base should be used in all studies in order that values at different stations shall be relatively comparable. In what follows generally, the United States Weather Bureau normal period 1878–1927 has been used, except in special cases where another base is used and noted.

In his classical paper* "On Mean or Average Rainfall," Sir Alexander

[1]Rainfall of U. S., *Rep. Ch. Wea. Bu.* 1896–97, p. 319.
[2]*Proc. Inst. Civ. Eng.*, 155, p. 293.
[3]*Quart. Jour. Roy. Met. Soc.* 5, 47, 198.
[4]Rainfall Atlas of the British Isles.
[5]Monthly Weather Review Supplement 34.
**Proc. Inst. Civ. Eng.*, 109 (1892), p. 89.

R. Binnie states that an average based on a five years' record might be subject to an error of 15 per cent.; on a 10 years' record, 8.25 per cent.; on a 25 years' record, 3.25 per cent.; on a 35 years' record, 1.8 per cent. In his report on "Rainfall in the United States,"* Henry gave the deviations from normal with varying lengths of record based on long-term rainfall records at New Bedford, Cincinnati and St. Louis; for 10-year series +16 per cent. and −11 per cent. for New Bedford, +20 per cent. and −17 per cent. for Cincinnati, and +17 per cent. and −13 per cent. for St. Louis. For a 25-year period, the extreme variation was 10 per cent. for both New Bedford and St. Louis. From his study, Henry concluded that "at least 35 to 40 years continuous observations are required to obtain a result that will not depart more than ±5 per cent. from the true normal, even if the register be continued indefinitely," the *average* variation of a 25-year period being about ±5 per cent. and ±3 per cent. for a period 40 years in length.

The first step in the study of the rainfall records for the Hartford purpose was concerned in establishing a normal which would be as near as possible to the ideal. From consideration of the longer records available, the study was carried into the shorter record of the later developed local watersheds ("Nepaug" and "East Branch"), with the purpose of ascertaining what might be the probability of more serious droughts and consequent lower run-off than had been experienced during the years of record (1912–32). This work was considered advisable on account of the discrepancy between the estimates made in 1912 concerning yield of the then proposed "Nepaug" source, based on the Sudbury and Wachusett records of the Boston Metropolitan Supply, and actual experience since and during the 20-year period of operation that followed its completion.†

When the present study was first undertaken, it was expected to use long period averages, but as the work continued and extended over several years, it was found there were such marked fluctuations in rainfall from year to year as to alter this figure so appreciably that it was impracticable for use.

To illustrate these difficulties: In Figure 9 are shown three recognized methods of approaching a normal; (1) the variation in the successive arithmetical averages caused by annual fluctuations; (2) the trend of the average computed by ordinary least-square methods, and (3) the results from computations along the lines suggested by Clough‡ and designated "zero sum" method. While the last process seemed to be tending toward the most stable figure, it also showed such fluctuations as to cause it to be rejected for the present purpose, which was to arrive at some figure which would be stable and reasonably near the ideal.

The wanderings of the average, computed by the method of dividing the total of the records by their number, is evident from curve (1) Figure 9,

*Rep. Ch. Wea. Bur. 1896–98, p. 219.

†59th Ann. Rep. Bd. Wat. Comm., Hartford, Conn. (1912–13), p. 31 and Plate 4.

‡H. W. Clough, *Mo. Wea. Rev.*, Aug. 1923, p. 391.

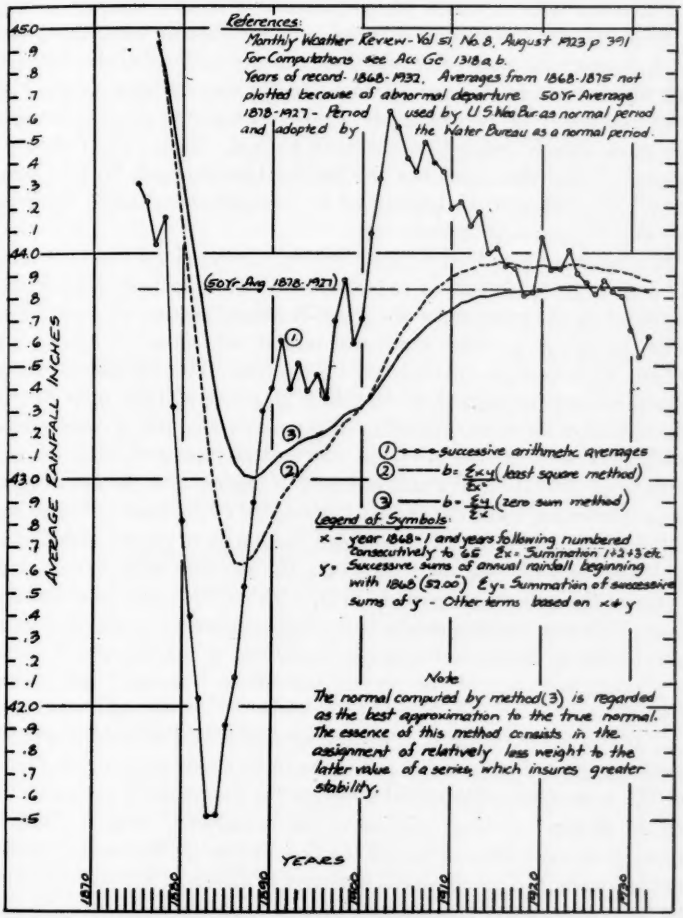

References:
Monthly Weather Review - Vol 51, No. 8, August 1923 p 391
For Computations see Acc Ge 1318 a, b.
Years of record: 1868-1932. Averages from 1868-1875 not plotted because of abnormal departure. 50 Yr Average 1878-1927 - Period used by U S Weather Bur as normal period and adopted by the Water Bureau as a normal period.
(50 Yr Avg 1878-1927)
AVERAGE RAINFALL INCHES
YEARS
1870
1880
1890
1900
1910
1920
1930
① successive arithmetic averages
② b = Σxy / Σx² (least square method)
③ b = Σy / Σx (zero sum method)
Legend of Symbols:
x - year 1868 = 1 and years following numbered consecutively to 65 Σx = Summation 1+2+3 etc.
y = Successive sums of annual rainfall beginning with 1868 (52.00) Σy = Summation of successive sums of y - Other terms based on x & y
Note
The normal computed by method (3) is regarded as the best approximation to the true normal. The essence of this method consists in the assignment of relatively less weight to the latter value of a series, which insures greater stability.

FIG. 9.— NORMAL RAINFALL AT RESERVOIR NO. 1, WEST HARTFORD COMPUTED BY THREE METHODS:

1. Successive Arithmetic Averages.
2. Least-square Method.
3. Zero Sum Method.

with extreme values of 41.52 in. after 16 years and 44.63 in. after 36 years. Since the high point in 1903, there has been a gradual falling off, so that in 1932, after 65 years of record, the figure obtained by this method is 43.63, just 1 in. below what it was 29 years ago, and 0.09 in. less than one year ago.

As stated for the studies of rainfall in the British Isles, the average rainfall during some particular period was chosen and called the "normal," which was not established for all time. It has already been changed once and will probably be revised again when accumulated records indicate a figure more closely related to the true normal. It has been shown by Glasspoole,* that the rainfall of the British Isles for each 35-year period, 1868 to 1921, varied from this normal by a maximum of only 1.5 per cent. above and 0.6 per cent. below.

For the West Hartford (Conn.) station, the mean for the U. S. "Normal" period (1878–1927) is 43.84 in. (43.845). This has been designated for the present as the normal for the West Hartford station and will be considered the datum to which studies of rainfall for the water supply of the Hartford Metropolitan District will be referred. The rainfall of the year 1932 was among the highest for the West Hartford station; only 10 others in the record of 65 years, exceeding this year in amount of precipitation. The second lowest rainfall of record was that of 1930 with 34.11 in. which was the same as that of 1879 and only 0.57 in. higher than the lowest record. It is an interesting coincidence that the rainfall of the year of beginning of the 50-year period (1883–1932) included the lowest of record with 33.64 in. (1883), and that of 1920, with 56.95 in., the highest, while the rainfall of the year of the end of this period (1932) with 49.75 in. was also one of the highest. This combination results in the highest average of the 16 successive 50-year series in the period; namely, 44.10 in., or 0.25 in. above normal. The relative positions of the several periods to "normal" are given in Table 25.

Referring to the method of arithmetical averages which is much more common usage, the relationship to the established normal shown in Figure 9 gives the successive arithmetical averages for the years of record at West Hartford station and their relation to the established normal. From this diagram, it appears that, excluding the first 21 years of the record, there are no deviations in the accumulated averages in excess of 1.8 per cent. above and 1.2 per cent. below the assigned normal of 43.84 in. In order to establish the reliability of the average of various years of record, however, the matter was investigated somewhat along the lines charted by Sir Alexander R. Binnie, in his classical treatise on average rainfall.† The method used in this study, however, follows directly that of Glasspoole‡ in that it uses every 50-year period within the record period rather than the consecutive period method of Sir Alexander Binnie. The relation of these two methods to each other is exemplified in Figure 10. The curve delineated by the full line represents averages for each 10-year period, while the dotted lines indicate

Trans. Inst. Water Eng., 29, p. 3. †*Proc. Inst. Civ. Eng.*, 109, (1892). ‡Loc. Cit.

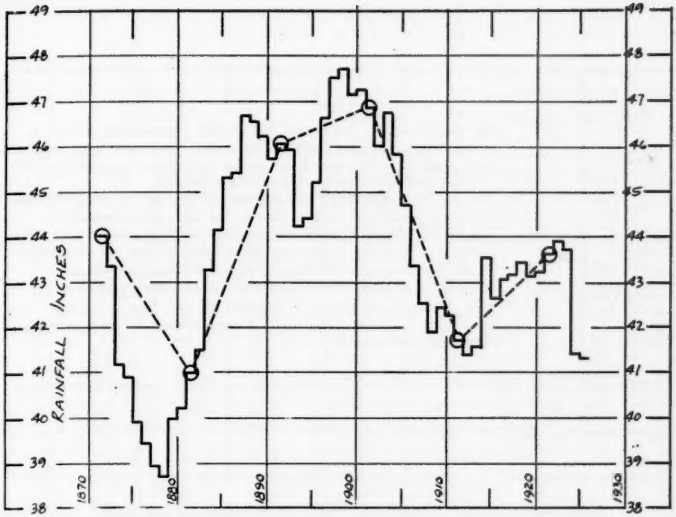


FIG. 10.— RAINFALL AT RESERVOIR NO. 1, WEST HARTFORD; 10-YEAR RUNNING AVERAGES AND CONSECUTIVE 10-YEAR PERIODS.

The value plotted for each year represents an average of the four preceding years, the calendar year at which the value is plotted and the five years following.

TABLE 24.— RAINFALL AT WEST HARTFORD FOR EACH 50-YEAR PERIOD, 1868–1932. Both in figures and as a per cent. of the average for the U. S. normal period.

Period.	50-Year Mean.	Per cent. of Normal.	Period.	50-Year Mean.	Per cent. of Normal.
1868–1917	43.93	100.2	1876–1925	43.80	99.9
1869–1918	43.65	99.6	1877–1926	43.74	99.8
1870–1919	43.42	99.0 (*min.*)	1878–1927*	43.84	100.0
1871–1920	43.77	99.8	1879–1928	43.76	99.8
1872–1921	43.56	99.3	1880–1929	43.92	100.2
1873–1922	43.60	99.4	1881–1930	43.87	100.1
1874–1923	43.79	99.9	1882–1931	43.85	100.0
1875–1924	43.68	99.6	1883–1932	44.10	100.6 (*max.*)

*U. S. Normal Period.

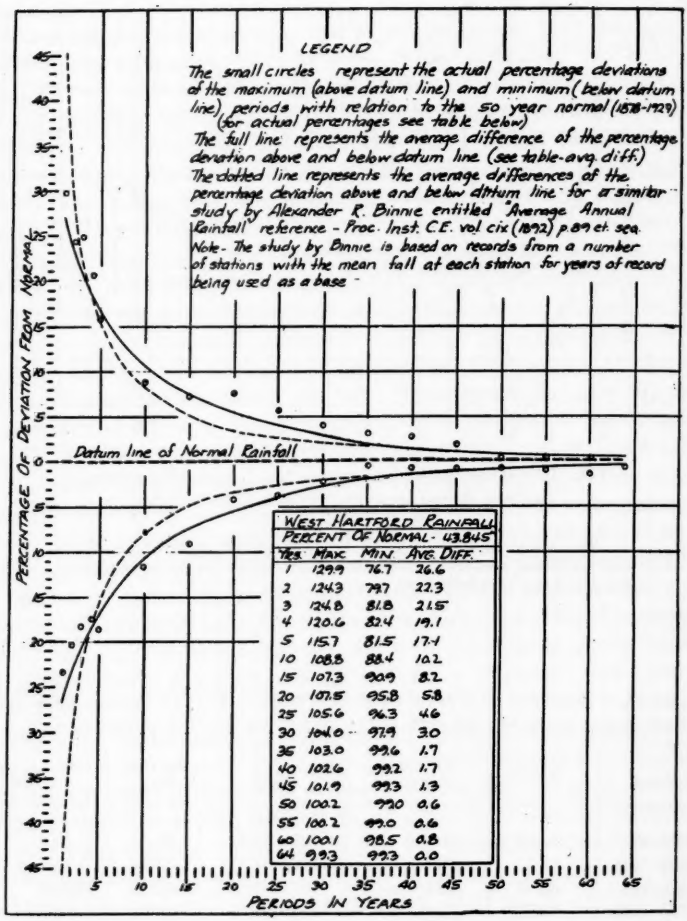

LEGEND
The small circles represent the actual percentage deviations of the maximum (above datum line) and minimum (below datum line) periods with relation to the 50 year normal (1878-1927) (for actual percentages see table below)
The full line represents the average difference of the percentage deviation above and below datum line. (see table-avg. diff.)
The dotted line represents the average differences of the percentage deviation above and below datum line for a similar study by Alexander R. Binnie entitled "Average Annual Rainfall" reference - Proc. Inst. C.E. vol cix (1892) p.89 et. seq.
Note - The study by Binnie is based on records from a number of stations with the mean fall at each station for years of record being used as a base
Datum line of Normal Rainfall
PERCENTAGE OF DEVIATION FROM NORMAL
PERIODS IN YEARS
WEST HARTFORD RAINFALL
PERCENT OF NORMAL - 43.845
Yrs. Max. Min. Avg. Diff.
1 129.9 76.7 26.6
2 124.3 79.7 22.3
3 124.8 81.8 21.5
4 120.6 82.4 19.1
5 115.7 81.5 17.1
10 108.8 88.4 10.2
15 107.3 90.9 8.2
20 101.5 95.8 5.8
25 105.6 96.3 4.6
30 104.0 97.9 3.0
35 103.0 99.6 1.7
40 102.6 99.2 1.7
45 101.9 99.3 1.3
50 100.2 99.0 0.6
55 100.2 99.0 0.6
60 100.1 98.5 0.8
64 99.3 99.3 0.0

FIG. 11.— DEVIATION FROM THE NORMAL RAINFALL (50-YEAR AVERAGE, 1878–1927) FOR VARYING PERIODS OF OBSERVATION AT WEST HARTFORD.

TABLE 25.— NEPAUG WATERSHED RELATION RUN-OFF TO RAINFALL.

Years.	Storage Period.		Per cent.	Growing Period.		Per cent.	Replenishing Period.		Per cent.	Per cent. Run-off Rainfall Total.
	Rainfall Inches.	Run-off Inches.		Rainfall Inches.	Run-off Inches.		Rainfall Inches.	Run-off. Inches.		
1912–13	24.74	16.85	68.1	7.63	1.26	16.5	19.44	7.45	38.3	49.3
14	20.62	18.91	91.6	10.13	1.95	19.2	7.37	1.43	19.4	58.5
15	19.96	14.14	70.8	17.78	4.32	24.3	10.01	3.88	38.7	46.8
16	18.64	17.72	95.2	11.94	3.07	25.7	9.51	2.00	20.9	56.8
17	19.47	15.33	78.7	14.22	4.46	31.4	10.12	4.92	48.6	56.4
18	20.57	15.72	76.5	10.10	2.28	22.6	10.70	2.94	27.5	50.6
19	26.43	19.52	73.7	8.97	2.22	24.7	13.19	4.44	33.7	53.9
20	20.84	21.41	102.7	14.74	5.64	38.3	13.15	[illegible]	37.7	65.7
21	22.49	19.44	86.5	10.45	2.59	24.8	10.54	[illegible]	18.3	55.1
22	18.66	14.68	78.7	14.88	3.49	23.5	8.49	2.96	34.9	50.3
23	23.44	18.38	78.2	8.02	1.77	22.1	12.98	2.96	22.8	52.0
24	24.30	19.74	81.2	7.99	2.10	26.3	8.86	1.87	21.1	57.6
25	18.70	12.88	68.8	11.99	1.49	12.4	11.46	2.74	23.9	40.6
26	16.98	14.24	84.0	9.75	1.34	13.7	14.17	4.27	30.1	48.5
27	17.95	14.80	82.5	16.17	5.42	33.6	15.58	8.83	56.6	58.5
28	20.69	16.91	81.6	17.25	8.21	47.6	6.09	3.68	60.5	65.4
29	25.35	17.91	70.6	6.03	1.11	18.4	11.33	1.88	16.6	49.0
30	17.71	10.16	57.0	10.68	1.33	12.5	8.63	1.05	12.2	33.9
31	20.36	11.21	55.0	10.75	3.58	33.3	4.45	0.49	11.0	43.0
1931–32	19.43	9.79	50.4	13.78	1.35	9.8	17.76	6.78	38.2	35.2
Totals.	417.33	319.74	..	233.25	58.98	..	223.83	71.46	..	..
Means.	20.86	15.98	76.6	11.66	2.95	25.3	11.19	3.57	31.9	51.5*
Per cent. of Annual Mean.	47.9	70.9	..	26.8	13.1	..	25.7	15.8	..	..

Mean Annual Rainfall = 43.52 inches.
Mean Annual Run-off = 22.53 inches.

Storage Period	Dec.–May incl.	Rafter.
Growing Period	June–Aug. incl.	U. S. Geological Survey.
Replenishing Period	Sept.–Nov. incl.	W. S. & Ir. Paper, No. 80, p. 16.

*Year December to November inclusive. Calendar year the percentage of $\frac{\text{Run-off}}{\text{Rainfall}}$ = 51.8 inches.

consecutive 10-year averages. The difference in information obtained is apparent.

This tabulation shows a variation of from 0.6 per cent. above (1883–1932) to 1.0 per cent. below.

Figure 11 is presented as offering a concise comparison of the reliability of rainfall records of varying lengths, and follows in form a diagram prepared by Sir Alexander Binnie in his paper already referred to. The vertical scale of the diagram shows deviations from normal in per cent. of that number and the horizontal scale gives the years of record. The small circles represent actual percentage deviations, the full line, the average difference in percentage deviation above and below for any period of record, and the dotted line similar information computed by Sir Alexander based on records of rainfall studied by him.* The table below the diagram gives extreme and average deviation from normal in per cent. of normal.

From this exposition, it appears that any good rainfall record similar to that from the West Hartford station for a 25-year period is probably reliable on the average within 4.6 per cent. of normal with limits of 5.6 per cent. above and 3.7 per cent. below that line, while, for a 50-year period, the average deviation above or below the line is only 0.6 per cent. In working up this diagram, "running averages" were computed for every 5-year sequence of the record, 1868–1932 inclusive, that is, 65 5-year periods covering every possible consecutive five-year stretch. Similar computations were made for all of the 10, 15, 20, . . . 55, 60-year periods. Reducing these to per cent. of the given 50-year normal, results in Figure 11 with the extreme durations shown in the table at the bottom of this diagram.

While an average of a number of consecutive records,— say twenty,— taken at random from the records, that is, starting with any year, might as a matter of pure chance in selecting the date of beginning approach very closely to the true normal, no particular reliance can be placed on such a result. For example, taking the 20-year period, 1880–1899, of the West Hartford record, the average was 43.77 in., or only 0.07 in. below the 50-year normal, but other averages in this series run as high as 47.14 and as low as 41.99 in.; again, taking every 25-year period, for the period 1885–1909, the average was 5.6 per cent. above normal (2.44 in.) and for the period 1907–1931 3.7 per cent. below normal (1.62 in.), with an average departure (error) of 4.6 per cent. above or below normal. That is, had the given record started in 1885 and ended with 1909, an average of 46.28 in. would have been obtained, and if started in 1907, the average for 25 years would have been 42.23 in., a spread of 4.05 in., or nearly 10 per cent. of the average. (See Fig. 12.)

The common use of the month as the unit for compiling hydrological data is an undesirable one, on account of the difference in the number of days in the calendar periods. Rafter† recognizing this condition divided the year into three periods, calling them the storage period (Dec.–May),

Proc. Inst. Civ. Eng., 109, Sect. 1 (1892), p. 33. †*U. S. Geol. Surv.*, Wat. Sup. Paper 80.

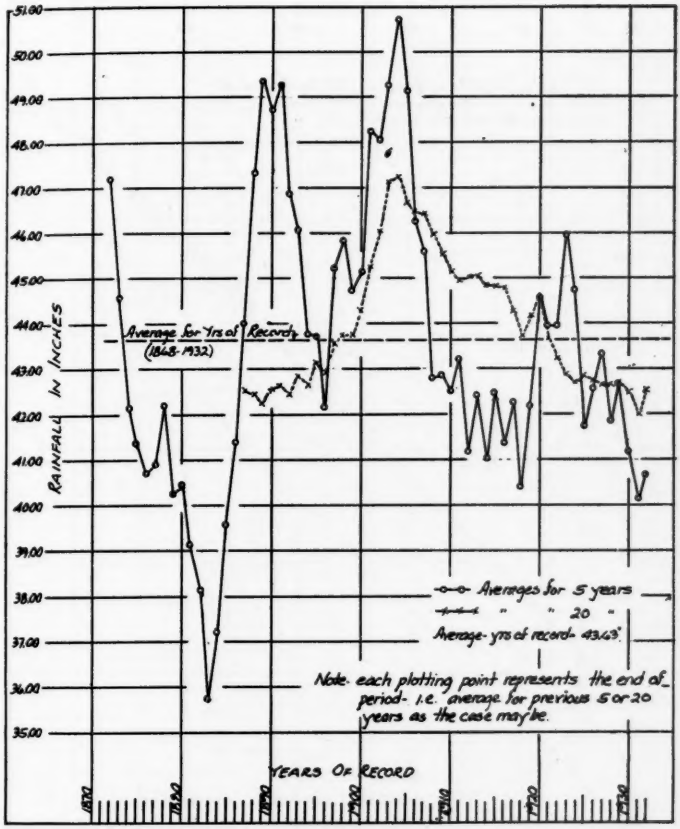


FIG. 12.— RUNNING AVERAGES FOR 5 AND 20 YEARS OF WEST HARTFORD RAINFALL, YEARS OF RECORD (1868–1932).

Circles connected by full line (starting in 1872) = 5-year averages.
Crosses connected by dotted line (starting in 1887) = 20-year averages.
Average for Years of Record = 43.63 in.

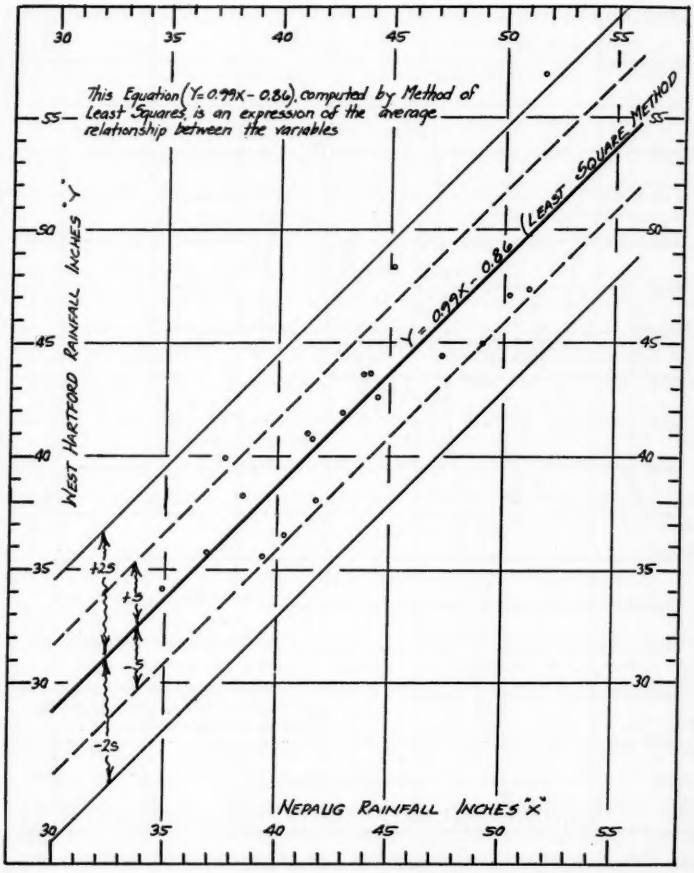


FIG. 13.— SCATTER DIAGRAM SHOWING RELATIONSHIP BETWEEN RAINFALL AT WEST HARTFORD AND NEPAUG.
The Standard Error (in this case 2.87 in.) measures the variation in absolute terms.

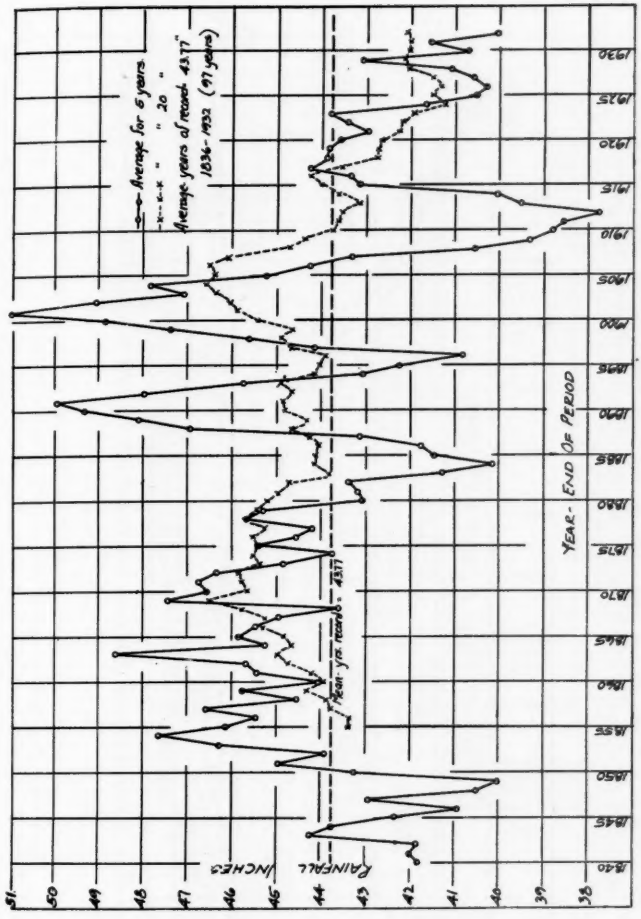


FIG. 14.— FIVE- AND TWENTY-YEAR RUNNING AVERAGES OF RAINFALL AT AMHERST, MASS.

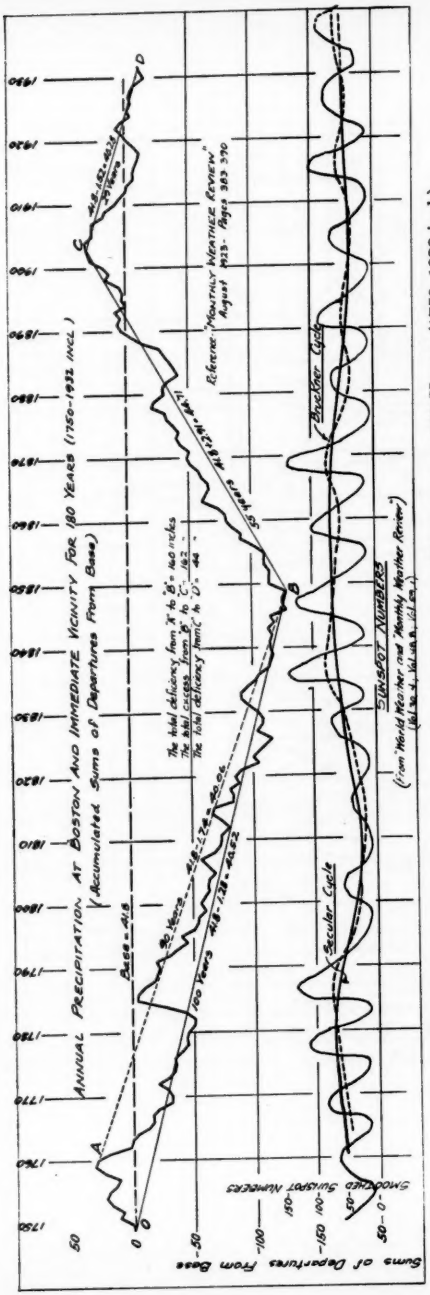


FIG. 15.— ANNUAL PRECIPITATION AT BOSTON AND IMMEDIATE VICINITY FOR 180 YEARS (1750–1932 incl.).

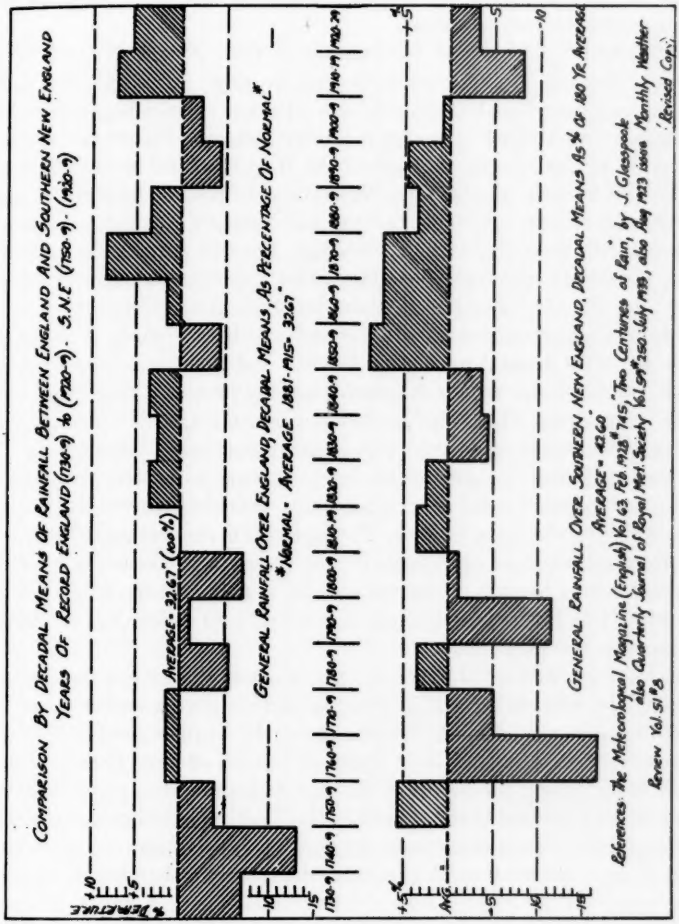


FIG. 16.—RAINFALL COMPARISON BY DECADAL MEANS, ENGLAND AND SOUTHERN NEW ENGLAND.

the growing period (June–Aug.) and the replenishing period (Sept.–Nov.). See Table 25. Both Augot in France and Mill in England have remarked this condition in their studies and have taken some steps to obviate the trouble.

The question naturally arises what then is the relative position to its normal of the comparatively short-time 20-year period at Nepaug for which observations are available.

On account of the close relationship of the "Nepaug" and "West Hartford" rainfall, it seems probable that no great error will arise from using the vagaries of the latter record as a criterion. Figure 13 presents this relationship investigated by methods of least squares. Figure 12 has been prepared from the running averages of the West Hartford records showing the five and 20-year trends. The West Hartford record, however, covers only 65 years and an even longer period was desired if it could be properly correlated with West Hartford and Nepaug. For this purpose the Amherst record, previously mentioned, has been used, carrying the record back to 1836.* (See Fig. 14.) Some weight also has been given to an inverse relationship to English conditions which was found in this study as shown in Figure 16. The decadal means for English and Southern New England rainfall records shown on this diagram, generally present a very interesting inverse relationship, which may or may not be indicative of a phenomenon of value in the study of drought conditions in Southern New England. It is to be noted that the general tendency appears to be complementary; that is, for excess rainfall in England and deficiency in Southern New England during the same periods. Perhaps this is chance; probably it is a meteorological sequence well known to men versed in the science of weather. Whatever it may be, it is of interest at least to note that for nearly a hundred years, this inverse correlation, if it may be so called, has continued with more or less persistence.

Rainfall records of 50 years or over in America are not particularly common, and reliable records of drought periods during earlier years are sorely needed in water-supply investigations. If it can be assured that the comparison of English and New England rainfall as here presented is a reliable index during the last 40 or 50 years, where records are considered, it may be also assured that this same relationship held during the earlier periods. If this is so, it would indicate that the last half century has been a period of more severe drought conditions than that of the prior 50 or more years, based on the English record for the latter period, which indicates comparatively low rainfall conditions, and, therefore, excess rainfall for Southern New England.

The figure showing the English periods follows the diagram and data found in the paper by Glasspoole in "Ten Centuries of Rain"[1] and "Rainfall Over the British Isles."[2] The data for New England rainfall were taken

*Goodnough, this JOURNAL, 44, (1930), p. 213. [1]*Meteor. Mag.* 1928, pp. 1–6.
[2]*Quart. Jour. Roy. Met. Soc.*, 59, July (1933).

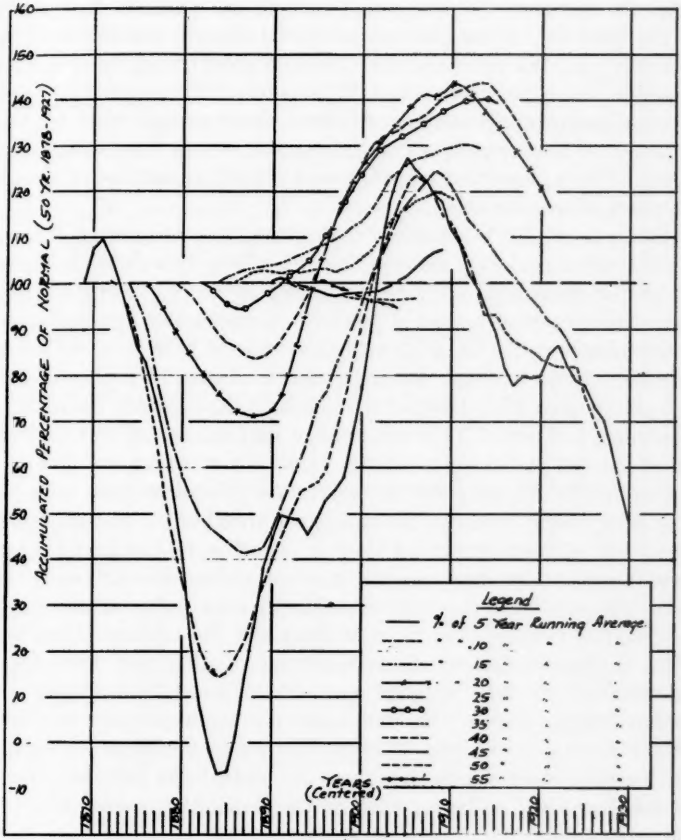


FIG. 17.— DEPARTURES FROM 50-YEAR NORMAL OF ANNUAL RAINFALL AT WEST HARTFORD FOR VARIOUS RUNNING AVERAGES.

from Marvin's article referred to in Figure 15 and Table 23. It is fair to say that the data for the earliest years of this table should be taken only as an indication of probable general rainfall conditions, since reliable individual records for the first 70 years or so are not available. Using the decadal periods of rainfall, Table 23 arranged from Marvin's[1] compilation (Fig. 15), it appears, however, that the period 1760–69 for Southern New England was probably one of the greatest individual drought periods experienced during the past 184 years and that a second period, apparently not much less severe, was experienced about 20 years later. The third lowest decade in the series apparently was that of modern times; namely, 1910–19. Of the last period we have records of both rainfall and run-off from several reliable sources, but it is found that years of lowest run-off are not always coincident with years of lowest rainfall.

So far as rainfall is concerned, a diagrammatic comparison of three of the more recent periods of drought, including 1910–19 is shown in Figure 3, and tabular statements are given in Tables 13 and 16. For Amherst the lowest 10-year period is that of 1905–14, corresponding approximately to the third low period of Table 23 with an average of 39.68 in. or 9.5 per cent. below the 97-year average. Referring now to Figure 12, it is evident that the 5-year period, 1879–1883, with 35.72 in. is the lowest of the series, and by reference to Figure 17, it is also evident that this period is at the bottom of a trough, the like of which has not since been experienced at this station (65 years). The 20-year period at this station (West Hartford) corresponding to the period of record at Nepaug is the lowest of the 65-year record at this station, with an average of 41.99 in., which is 1.85 in. or 4.2 per cent. below normal. The same relative position occurs also on the Amherst record, Figure 14. For practical water-supply work, however, the ranges in much shorter periods must be considered and the minima of the 5-year periods in Figures 12 and 14 are indicative of what may reasonably be expected on both the "Nepaug" and "East Branch" watersheds of the Hartford supply system. On this basis, one might assume the Nepaug probable normal to be about 44.30 in. The 5-year periods of the comparators, however, show clearly that there are much lower periods of rainfall, and therefore yield, to be expected on the Nepaug area than have as yet been experienced.

In water-supply investigations and in general meteorological work, the average or normal has little significance, except as a reasonably firm datum or base for reference. The position of the record, however, is of extreme importance in deciding on the reliability of a given period in relation to normal condition. As an illustration of this statement, Figure 17 is presented compiled from West Hartford rainfall records.

Trends in long-term rainfall are best shown diagrammatically by plotting accumulating deficiencies from normal. This method has been used considerably by British meteorologists, and, for America, a very instructive

[1]Loc. Cit.

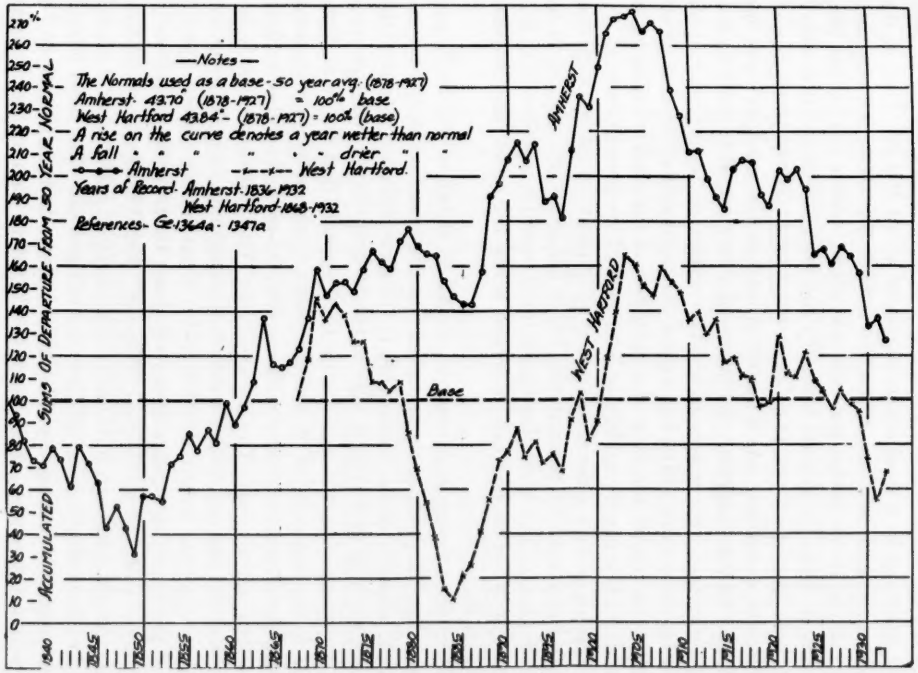

—Notes—
The Normals used as a base - 50 year avg. (1878-1927)
Amherst 43.70" (1878-1927) = 100% base
West Hartford 43.84" - (1878-1927) = 100% (base)
A rise on the curve denotes a year wetter than normal
A fall " " " " " drier "
Amherst
West Hartford
Years of Record - Amherst 1836-1932
West Hartford 1868-1932
References - Ge 1364a - 1347a
AMHERST
WEST HARTFORD
Base
ACCUMULATED SUMS OF DEPARTURE FROM 50 YEAR NORMAL

FIG. 18.— COMPARISON, WEST HARTFORD-AMHERST RESIDUAL MASS PERCENTAGE CURVES OF ANNUAL RAINFALL.

article is given by Marvin.* A diagram (Fig. 15) based on data in Marvin's paper, extended through 1932, is given herewith with his permission. Attention is called to some interesting features of this curve. From 1759 to 1849, during a period of 90 years, there was a total deficiency in rainfall of about 160 in. From 1849 to 1904, a period of 55 years, conditions were reversed, resulting in a total accumulation of about 162 in. That is, the total amount of gain and loss in the two periods was about the same, but the gain of the latter period per year was about double that of the first period. Since 1904, the general tendency has been downward at a rate of about 1.50 in. per year (total 44 in.), a rate not much different from that of the earlier 90-year period. As a matter of interest the sun-spot curve has been plotted on this diagram. As previously, no attempt is made in this paper to correlate with sun-spots or other cycles or to predict rainfall amounts for the coming years, but a guess is hazarded that the next period of deficiency in run-off will be in the early part of the decade beginning in 1940, with flush times the middle or later part of the present decade.

It appears to be a general rule noted by students of meteorology that the number of years with precipitation below the mean are more numerous than those above. The West Hartford rainfall record is in accord with this opinion, with 37 of its 65 years of record below the mean, and 28 years above (Fig. 2).

Referring to the general trend of rainfall as shown in Figure 18, and it is clear that the position of the record of a single station should be considered not alone but in its relationship to the meteorological scheme of the Cosmos in the long swings from high to low in order to get a true perspective. Comparing this chart with Figure 15, it appears that the West Hartford high at the beginning of the series is only a ripple on the upward trend of the long-period record, while the high at 1902 is a critical point coincident with the long-time records. The low also in the West Hartford record in the early part of the eighties, while of sufficient importance to make a distinct scar on its long-time record, nevertheless is a part of the general upward march of precipitation which culminated about 1904. With these facts in mind, it is evident that the 20-year "Nepaug" period is merely an incident in its life history, although fortunately that incident occurred at a critical period, *i.e.*, exceedingly high and low rainfall periods. The most critical period as regarding minimum yields would seem to be near the end of the long downward slope; *i.e.*, about point "B" 1849 in Figure 15 and similar date on Amherst curve (Fig. 18). Weber† records lack of rain and severe drought conditions around this point. "The drought of 1854 was undoubtedly more extensive and more destructive than any of those which had preceded it." From other sources, it would seem probable that for this part of the country the drought period in the middle of the 19th century was by far the most severe of any such periods since that time, including that of 1879–83, and while actual records of water yield are not available, it seems

Monthly Weather Review, August, 1923. †This JOURNAL, 44, (1930), pp. 11 and 12.

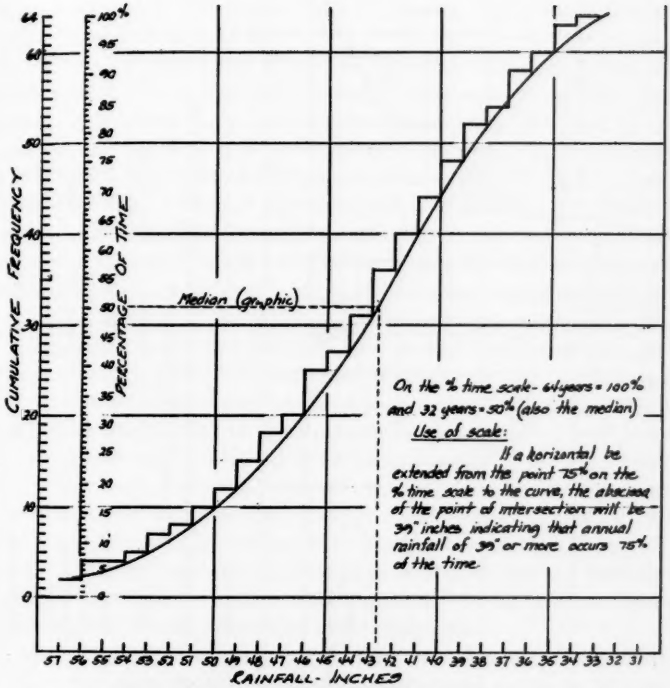

CUMULATIVE FREQUENCY
PERCENTAGE OF TIME
Median (graphic)
On the % time scale- 64 years = 100%
and 32 years = 50% (also the median)
Use of scale:
If a horizontal be extended from the point 75% on the % time scale to the curve, the abscissa of the point of intersection will be 39" inches indicating that annual rainfall of 39" or more occurs 75% of the time.
RAINFALL - INCHES

FIG. 19.— CUMULATIVE FREQUENCY DISTRIBUTION (OGIVE) OF RAINFALL AT RESERVOIR NO. 1, WEST HARTFORD (1868–1932).

Mean Annual Rainfall (1868–1931) = 43.54 in.
Computed Median = 42.50 in.
Average Rainfall 50 Years (1878–1927)* = 43.84 in.

*Period used by U. S. Weather Bureau as a "Normal."

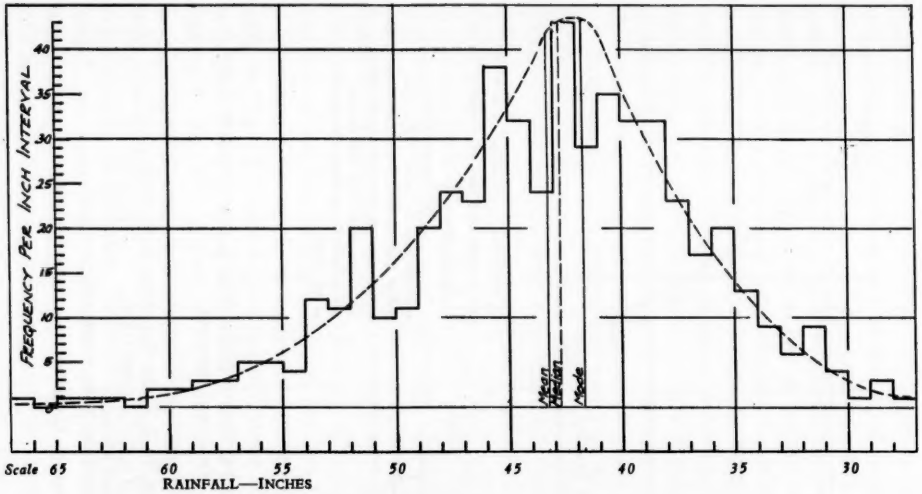


FIG. 20.— FREQUENCY DISTRIBUTION OF RAINFALL AT SELECTED STATIONS IN SOUTHERN NEW ENGLAND.

Station	Years	Period	Mean Rainfall Inches
1. West Hartford	64	1868–1931	43.54
2. Amherst	96	1836–1931	43.82
3. Springfield	84	1848–1931	43.59
4. Lowell	106	1826–1931	41.26
5. Waltham	107	1825–1931	42.08
6. Middletown	73	1859–1931	46.48
Total	530	Weighted Average	43.25

Mean = 43.26 in.; mode = 41.67 in.; median = 42.73 in.

desirable to consider the probabilities of this period in estimates for water supply. Unfortunately, rainfall records were not particularly complete over widespread areas at this time, and there were few, if any, records of run-off. In the Amherst record (1836–1932)* the lowest 5-year average was 37.93 in. (1909–1912), but this was only 0.13 in. lower than that of the period 1845–49 (38.06 in.), while, for the 5-year period 1880–84 (which is recorded as one of the most severe in modern water-works history) the average rainfall was 40.16 in.

Although it is probably correct, as scientists tell us, that there has been no appreciable change in general rainfall amounts for several thousand years, it is necessary for safe water-supply provision that some of the relatively smaller oscillations be given careful consideration. This matter can be studied by probability methods as so extensively used by the late Allen Hazen. (See Figs. 4 and 5.) Another method of presenting a picture of the march of rainfall and its probable variations is by the Ogive and Frequency curves used in statistical studies, Figures 19 and 20. In the former, the vertical scale is given in per cent. of time while the horizontal scale gives inches of rainfall. The use of the diagram is obvious; that is, a rainfall of 46 in. or more, has occurred twenty times in 64 years (31.2 per cent.), or on an average of nearly thirty times in a hundred years. Judging the future by the past, similar conditions may again be expected. Oftentimes, especially in cases where the number of observations making up the record is limited, the average, or mean, obtained by dividing the sum of the observations by the number, does not result in the information actually desired, on account of comparatively few items which may differ widely in amount. What is really desired is not the average size, but the most frequent size. This is called the "mode" and can be roughly approximated by the formula mode = mean − 3 (mean − median), the "median" being that amount which is half way in a series arranged in order of magnitude.

In the course of this study, the long-period rainfall record at West Hartford has been broken down and re-arranged in Table 11 into consecutive minimum rainfall periods, ranging by months up to 60 and also arranged by years for the five lowest periods. Two other tables are presented, Nos. 14 and 17, giving the rainfall and run-off minima for consecutive calendar periods on the Sudbury (Mass.) and Croton (N. Y.). These tables give also the average monthly run-off for the years of record for the minimum periods and the relation of the minimums to the averages. These data, as previously stated, show that calendar periods are not reliable indices of abnormal conditions.

As already stated, the West Hartford record of rainfall is a long one, sufficiently long, (65 years) to give reliable information on this score. Information concerning water yield from other sources, the Nepaug and East Branch systems, was the ultimate purpose of this study. On these watersheds, the record is only 21 years long and according to Figure 10, an answer

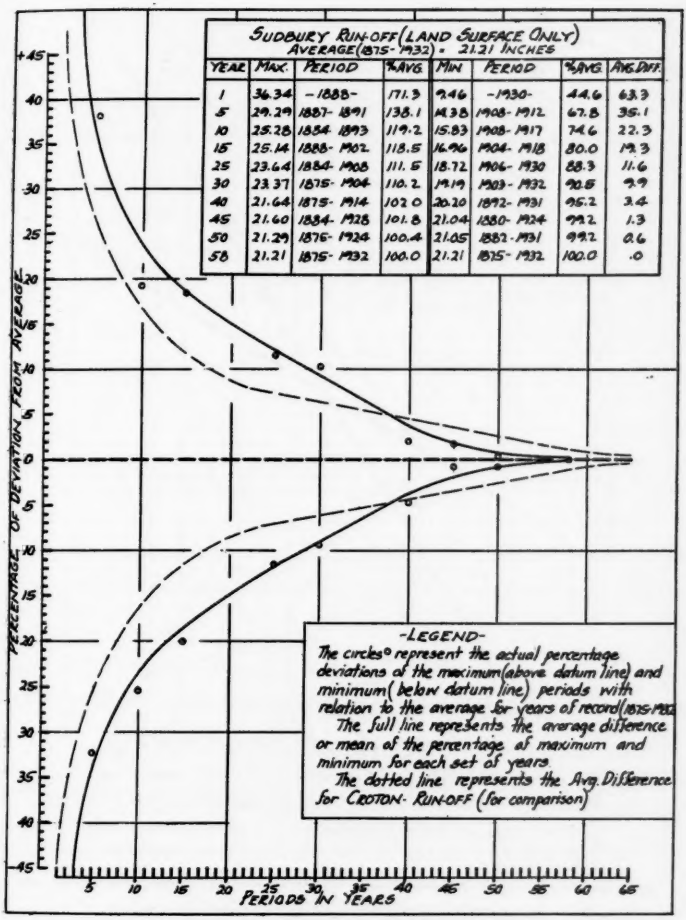
*This JOURNAL, 44, (1930), p. 213. Station record since.

to the question of long-period rainfall fluctuations cannot be expected with more accuracy than 6 per cent. (5.8 per cent.) above or below normal with the extremes as much as 7.5 per cent. above or 4.2 per cent. below normal. For run-off, there are even greater variations (Fig. 21). On the Nepaug watershed, with its 21-year record, the highest rainfall record was 49.85 in. in 1913, the lowest, 34.61 in. in 1930; half of the highest is 29.92 in. or 4.67 in. below the present low record. From the probability diagrams, Figure 4 and a similar study not shown, it appeared that the low West Hartford rainfall of 1883 (33.64 in.) might occur once in 29 years and the low 2-year average (1930–31), once in 83 years, while a 2-year average of 35.8 in., corresponding to the minimum 2-year rainfall period of record on the Nepaug (Table 10) would occur about once in fifty years, with a yield of about 37.5 per cent. of rainfall and 59.7 per cent. of the average for the years of record, the rainfall itself being 82.4 per cent. of the average. How many water-supply systems can weather a 2-year period with yield of watershed 60 per cent. below average?

Using least-square methods with Nepaug and West Hartford records, a "scatter" diagram was constructed with their relationship as shown in Figure 13 and the regressian equations determined. The correlation coefficient, working out to $+0.89$ with a probable error of $\pm$ 0.03, was deemed a sufficiently close relationship to warrant the reliability of deductions carrying the probable Nepaug rainfall record back at least to 1868. Although this computation indicated probability of no lower rainfall for Nepaug than that of 1930, the fact that West Hartford had six years below normal, 1879–84, with an average fall of 37.50 in., or 6.32 in. below normal, while the Nepaug probability was 35.8 in. for a 2-year average and 34.25 in. for West Hartford for the same period, made it desirable to continue the study for a still longer period. For this purpose, the Amherst record, which began in 1836, was examined in connection with the West Hartford record and the results of this study by least square methods indicated a sufficiently reasonable relationship between the two stations to warrant confidence in its use as a comparator. For the years of record at West Hartford, 1868–1932, the average annual rainfalls at Amherst and West Hartford were respectively 43.665 in. and 43.628 in., and deviations of -0.32 and -0.16 from the mean. (See Figs. 22 and 23.)

Beside the method of correlation between stations, some study has been made of the records of growth as shown in the annual rings of trees in the vicinity, with ages considerably longer than the rainfall records. Several trunks of trees have been examined which apparently have ages from 60 to over 150 years. A tentative result of one of these examinations is shown in Figure 24. The studies from the data obtained from this investigation are not yet complete, and, therefore, no record is here made, except the general statement of conformity by this means.

From the local data at hand and from the correlations of Amherst, West Hartford and Nepaug rainfall, as well as those of run-off and tree


SUDBURY RUN-OFF (LAND SURFACE ONLY)
AVERAGE (1875-1932) = 21.21 INCHES
PERCENTAGE OF DEVIATION FROM AVERAGE
PERIODS IN YEARS
-LEGEND-
The circles represent the actual percentage deviations of the maximum (above datum line) and minimum (below datum line) periods with relation to the average for years of record (1875-1932)
The full line represents the average difference or mean of the percentage of maximum and minimum for each set of years
The dotted line represents the Avg. Difference for CROTON RUN-OFF (for comparison)

YEAR	MAX.	PERIOD	%AVG.	MIN	PERIOD	%AVG.	AVG. DIFF.
1	36.34	-1888-	171.3	9.46	-1930-	44.6	63.3
5	29.29	1887-1891	138.1	14.38	1908-1912	67.8	35.1
10	25.28	1884-1893	119.2	15.83	1908-1917	74.6	22.3
15	25.14	1888-1902	118.5	16.96	1904-1918	80.0	19.3
25	23.64	1884-1908	111.5	18.72	1906-1930	88.3	11.6
30	23.37	1875-1904	110.2	19.19	1903-1932	90.5	9.9
40	21.64	1875-1914	102.0	20.20	1892-1931	95.2	3.4
45	21.60	1884-1928	101.8	21.04	1880-1924	99.2	1.3
50	21.29	1876-1924	100.4	21.05	1882-1931	99.2	0.6
58	21.21	1875-1932	100.0	21.21	1875-1932	100.0	.0

FIG. 21.— DEVIATION FROM THE AVERAGE FOR VARIOUS PERIODS OF THE MAXIMUM AND MINIMUM RUN-OFF AT SUDBURY, MASS.

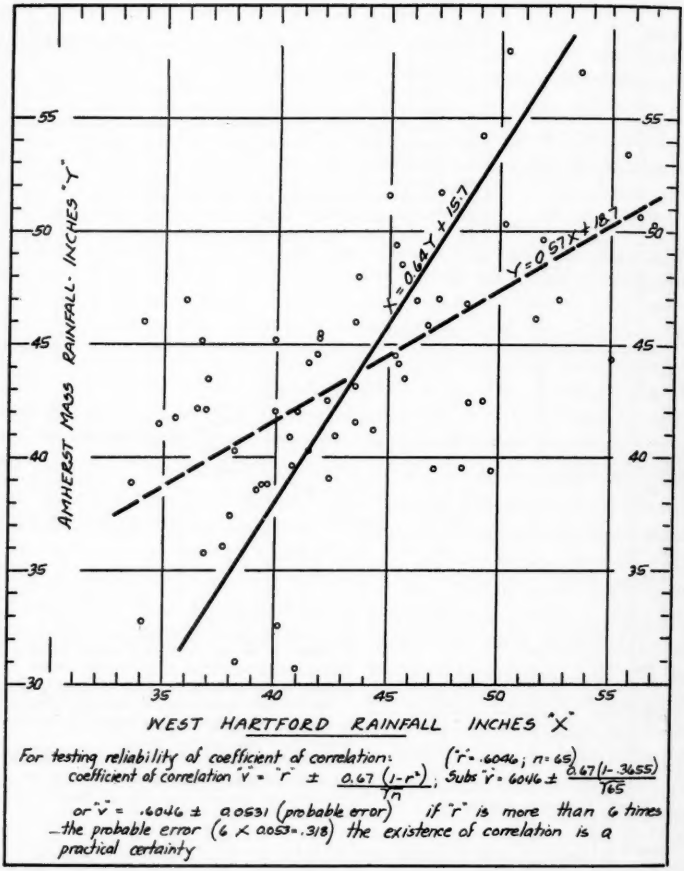

AMHERST MASS RAINFALL · INCHES "Y"
WEST HARTFORD RAINFALL INCHES "X"
55
50
45
40
35
30
35
40
45
50
55
X = 0.64Y + 15.7
Y = 0.67X + 18.7
For testing reliability of coefficient of correlation:
coefficient of correlation "v" = "r" ± 0.67 (1-r²)/√n ; ("r" = .6046; n = 65) Subs "v" = .6046 ± 0.67(1-.3655)/√65
or "v" = .6046 ± 0.0531 (probable error) if "r" is more than 6 times the probable error (6 × 0.053 = .318) the existence of correlation is a practical certainty

FIG. 22.— REGRESSION EQUATIONS, WEST HARTFORD–AMHERST, MASS.

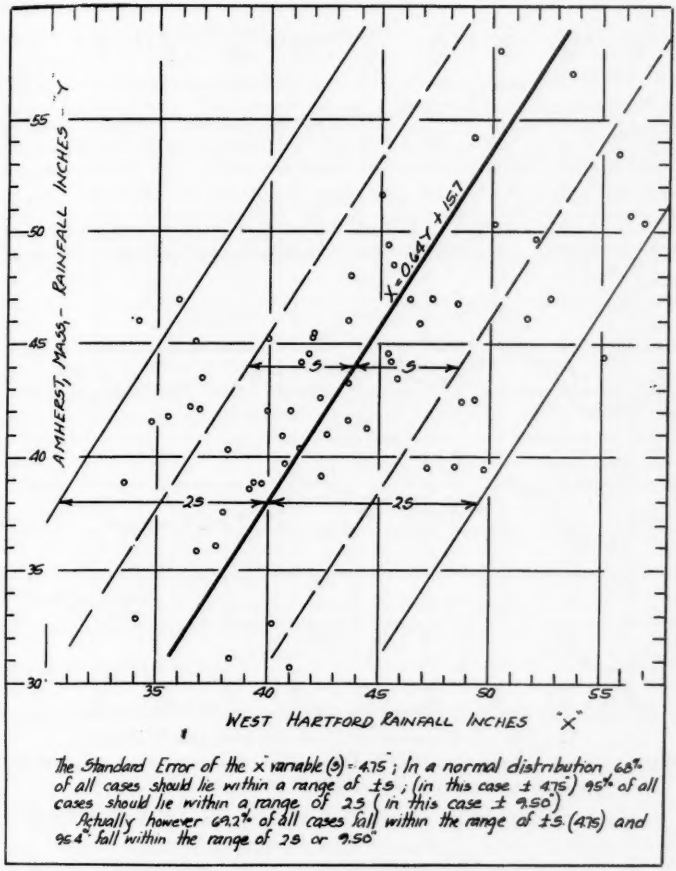

AMHERST MASS. - RAINFALL INCHES - "Y"
55
50
45
40
35
30
35
40
45
50
55
WEST HARTFORD RAINFALL INCHES "X"
X=0.64Y+15.7
8
s
s
2s
2s
The Standard Error of the "x" variable (s) = 4.75"; In a normal distribution 68% of all cases should lie within a range of ±s; (in this case ± 4.75") 95% of all cases should lie within a range of 2s (in this case ± 9.50")
Actually however 69.2% of all cases fall within the range of ±s (4.75) and 95.4% fall within the range of 2s or 9.50"

FIG. 23.— SCATTER DIAGRAM SHOWING RELATIONSHIP BETWEEN RAINFALL AT WEST HARTFORD AND AMHERST.

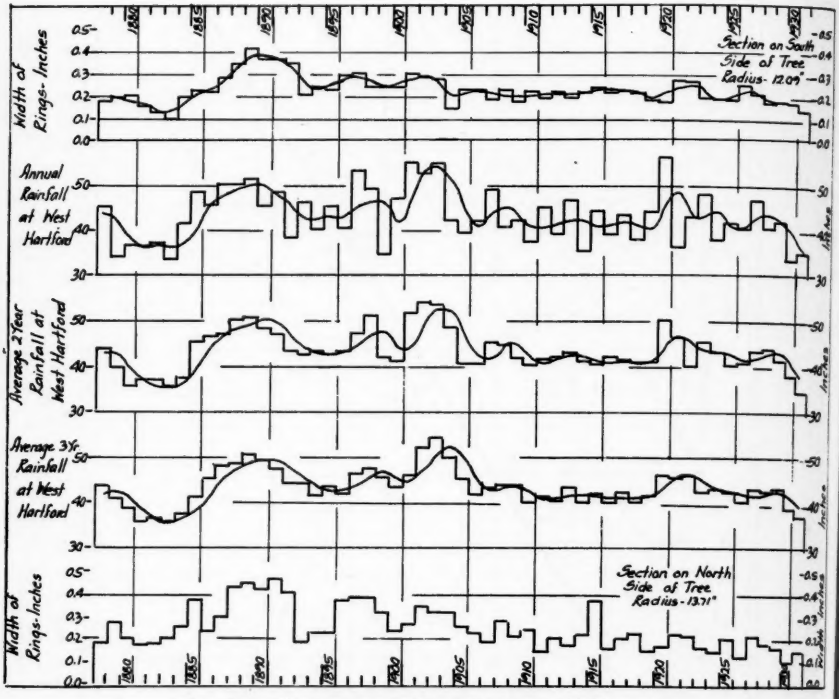

Width of Rings - Inches
Section on South Side of Tree Radius - 12.09"
Annual Rainfall at West Hartford
Average 2 Year Rainfall at West Hartford
Average 3 Yr. Rainfall at West Hartford
Section on North Side of Tree Radius - 13.71"
Width of Rings - Inches

FIG. 24.— COMPARISON OF TREE GROWTH AND RAINFALL.
White pine cut in February, 1932 in Valley of West Branch of Farmington River.
Radius of trees: North side 31.71 in.; south side 12.09 in.

2-year moving average computed as $\frac{a+b}{2}$ and plotted for b year

3-year moving average computed as $\frac{a+2b+c}{4}$ and plotted for b year for tree rings and c year for rainfall.

growth, it appears that probably there has been no drought period in Central Connecticut during the past fifty years with relation to water-supply works that has exceeded in severity that of the period 1879–84. This period and that of 1908–1911, it will be recalled, were thoroughly investigated by a Committee of this Association* and reported in 1914. Those studies indicate, however, that it is reasonable to expect much more severe conditions of low run-off in the area now being developed for the supply of water to the Hartford district than have been experienced in the past 21 years of record, and that a much longer record in this locality is necessary in planning, with reasonable conservatism, the water supply of a large city. Reports and opinions based on records of less than a half century at least should be definitely qualified in this respect.

In the monograph,† previously referred to, Rafter suggested dividing

TABLE 26— NEPAUG RIVER WATERSHED.
Minimum Rainfall and Run-off Statistics.
(Period of Record — April 1912–December 1932.)

Minimum Rainfall Periods, with Corresponding Periods of Run-off.

Months.	Period.	Rainfall.		Run-off.		Per cent. of Collection.
		Inches.	Per cent. of Average.[2]	Inches.	Per cent. of Average.[3]	
12	July 1931–June 1932	33.55	77.1	11.72	52.0	34.9
24	Jan. 1930–Dec. 1931	71.72	82.4	26.91	59.7	37.5
36	June 1929–May 1932	109.37	83.7	40.60	60.1	37.2
48	Oct. 1928–Sept. 1932	154.24	88.6	61.56	68.3	39.9
60	Aug. 1921–July 1926	205.35	94.3	102.55	91.0	49.8

Minimum Run-off Periods, with Corresponding Periods of Rainfall.

Months.	Period.	Rainfall.		Run-off.		Per cent. of Collection.
		Inches.	Per cent. of Average.[2]	Inches.	Per cent. of Average.[3]	
12	[1]Mar. 1930–Feb. 1931	35.23	81.0	9.43	42.0	26.8
24	April 1930–Mar. 1932	75.61	87.0	25.99	57.7	34.4
36	July 1929–June 1932	110.15	84.5	40.56	60.0	36.8
48	Oct. 1928–Sept. 1932	154.24	88.6	61.56	68.3	39.9
60	Jan. 1928–Dec. 1932	207.30	95.3	93.36	82.9	45.0

[1]Rainfall and Weather Conditions prior to Minimum 12 month period — (March 1930–February 1931): The Drought began in June 1929 and by December, the deficiency of Rainfall was 4.85 inches. Therefore the amount of water in Ground Storage was low as the Winter started. There was a noticeable lack of both frost and snow during the Winter thus setting the stage for a ready absorption of the comparatively light Spring rains which followed.

[2]Average Rainfall for Years of Record — April 1912–December 1932 = 43.52 inches.
[3]Average Run-off for Years of Record — April 1912–December 1932 = 22.53 inches.
Average Percentage of Collection Record — April 1912–December 1932 = 51.8 per cent.
Area of Watershed 23.9 square miles, Area of Nepaug Reservoir Watershed = 31.85 square miles.

*This JOURNAL, 28, (1914), p. 357.

†*U. S. Geo. Survey*, Wat. Sup. and Irr. Paper 80, p. 9.

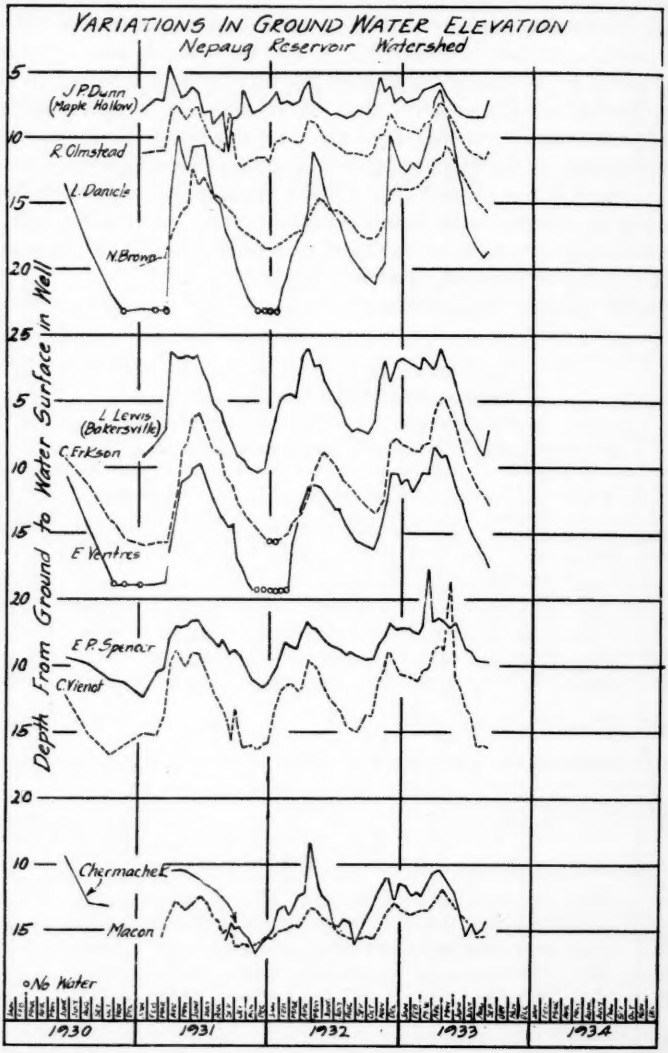


FIG. 25.— VARIATIONS IN GROUND WATER ELEVATION, NEPAUG RESERVOIR WATERSHED.

TABLE 27.— VARIOUS STATISTICAL MEASURES FOR MONTHLY RAINFALL AT RESERVOIR NO. 1 WEST HARTFORD.
(All Measures in Inches Unless Otherwise Noted.) ± ϕ ⊠

Month.	Average (1868–1932).	Normal 50 Year (1878–1927).	Median.	Mode — Approx.*	Maximum.	Minimum.	σ Standard Variation.	Actual Per cent. Within σ	Per cent. Co-efficient of Variation.	Per cent. Probable Error.
Jan.	3.44	3.52	3.23	2.81	3.48	1.00	1.56	72.3	45.0	3.77
Feb.	3.34	3.46	3.14	2.74	8.28	0.50	1.57	66.2	46.7	3.91
Mar.	3.79	3.60	3.29	2.29	9.38	0.17	1.86	67.7	48.5	4.06
April	3.37	3.37	3.03	2.35	11.17	0.73	1.83	76.9	54.0	4.52
May	3.64	3.55	3.34	2.74	9.10	0.20	1.90	70.8	51.6	4.32
June	3.33	3.11	3.07	2.55	10.81	0.15	1.89	76.9	56.5	4.73
July	4.04	4.31	3.83	3.41	15.14	0.66	2.26	76.9	55.7	4.66
Aug.	4.38	4.30	4.12	3.60	10.27	0.25	2.15	67.7	48.6	4.07
Sept.	3.51	3.67	2.98	1.38	10.88	0.25	2.39	80.0	67.5	5.65
Oct.	3.78	3.67	3.20	2.04	13.33	0.18	2.55	72.3	66.9	5.60
Nov.	3.69	3.67	3.40	2.82	8.30	0.74	1.88	70.8	50.7	4.25
Dec.	3.32	3.61	3.18	2.90	9.34	0.67	1.68	64.6	50.3	4.21
Statistical Measures for Annual Rainfall at Reservoir No. 1.										
Year	43.63	43.84	42.57	40.45	56.95	33.64	5.96	64.6	13.6	1.14

ϕ "Co-efficient of Variation"— ratio of Standard Variation to the Mean: *i.e.*

$$\frac{n\sqrt{\frac{v^2}{n-1}}}{\Sigma M} \quad \text{Substituting} — \quad \frac{65\sqrt{\frac{2279.165}{64}}}{2835.79} = \frac{65 \times 5.96}{2835.79} = 0.1366$$ co-efficient of Variation for Mean Annual Rainfall.

⊠ The Probable Error in the Mean Rainfall (due to variations in annual quantities) is found by Formula —

$$R = 0.6745\sqrt{\frac{\Sigma v^2}{n(n-1)}} = .6745\sqrt{\frac{2279.165}{65 \times 64}} = 0.499 \text{ inches.}$$

Probable Error of a single observation = "T" = $.6745\sqrt{\frac{\Sigma v^2}{n-1}}$ = .6745 x 5.96 = 4.020 inches.

± In a Normal distribution, when a distance equal to the "Standard Variation" is laid off on each side of the mean, about two thirds of all cases will be included. This column contains the actual percentage of cases within limits of Mean ±σ.

*The Formula for the approximate mode = mean — 3(mean — median).

N.B. — The Annual Figures are not totals, nor have any relation to the monthly figures.

Standard Variation .. = $\sqrt{\frac{\Sigma v^2}{n-1}}$ where "n" = number of terms and "v" = variation from mean.

In order to find inches of probable error — multiply per cent. of error by the respective means.

Average; *Or Arithmetic Mean.* The sum of the whole number of samples divided by the number of samples. Affected by every measure in a series.

Median. That value of a sample which is midway in an array, arranged in order of magnitude. It is a measure which is not affected by the magnitude of extreme deviations from the average.

Mode: That value of a sample which is the most common of all values in the total array. It is the average most typical of the distribution, being located at the point of greatest concentration. The approximate mode is easy to locate by the formula — Mode = Mean — 3 (Mean — Median), however the determination of the true mode requires extended calculation.

Standard Deviation. $ In computing this measure, the deviations of the individual items from the arithmetic mean are squared, totaled, the mean of the squared deviations obtained, and the square root of this mean extracted. It is the square root of the mean of the squared deviations. The measure is affected by the value of every observation. — When a distance equal to the standard deviation is laid off on each side of the mean, in a normal distribution, about two thirds of all cases will be included. When a distance equal to twice the standard d eviation is laid off on each side of the mean approximately 95% of all cases will be included. Similarly a distance equal to three times the standard deviation should include 99% of all cases. It is therefore a measure of the variation from the arithmetic mean.

Normal: This Period (1878–1927) 50 Years, is the one used by The U. S. Weather Bureau as a "Normal" Period.

Probable Error: The probable error, is a measure of dispersion, derived from the fact that the probability that a given observation will vary from the mean of all observations by an amount greater than the probable error is exactly ½.

the calendar year into periods which would more fully conform to water-supply use. Such a division as he suggested has been made up for the "Nepaug" watershed and is given as Table 25.

Illustrating the fact that excess or deficiency periods in rainfall and run-off are not concurrent, Table 26 is presented, made up from "Nepaug" records of the past 21 years. It is to be noted that the 12-month period of minimum run-off — March 1930 — February 1931 — preceded by over

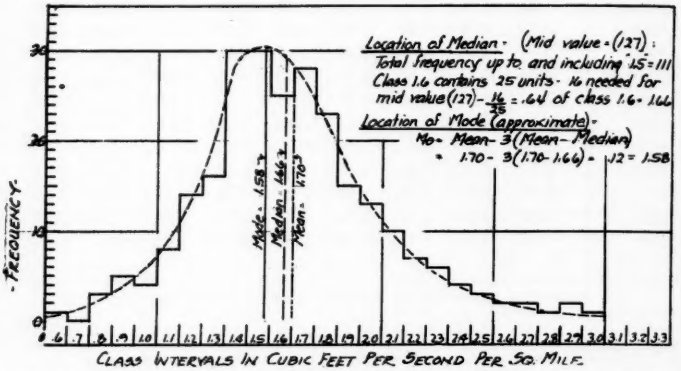

Location of Median - (Mid value - (127)
Total frequency up to and including 1.5 = 111
Class 1.6 contains 25 units - 16 needed for
mid value (127) - 16/25 = .64 of class 1.6 - 1.66
Location of Mode (approximate) -
Mo = Mean - 3(Mean - Median)
= 1.70 - 3(1.70 - 1.66) = .12 = 1.58
Mode - 1.58.3
Median - 1.66.2
Mean - 1.70.3
FREQUENCY
CLASS INTERVALS IN CUBIC FEET PER SECOND PER SQ. MILE

FIG. 26.— FREQUENCY DISTRIBUTION OF MEAN ANNUAL RUN-OFF IN CUBIC FEET PER SECOND PER SQUARE MILE FOR SELECTED STATIONS IN SOUTHERN NEW ENGLAND.

Station	Period	Years	Run-off Cu. Ft. per Sec. per Sq. Mile
Croton	1868–1932	65	1.72
Sudbury	1875–1932	58	1.56
Wachusett	1897–1932	36	1.75
Nepaug	1913–1932	20	1.67
Holyoke	1908–1932	25	1.80
Abbott Run	1907–1931	25	1.55
Little River	1908–1931	24	1.98
Total	——	253	——
Weighted Average		——	1.70

All figures for land surface only except Little River with 1.6 per cent. water surface.

a year the period of minimum rainfall during a similar period. A glance at the monthly record of the West Hartford station, Table 1, shows clearly the cause; that is, a period of deficient rainfall beginning June 1929 and continuing through January and February, 1930. This resulted in draft on ground-water storage during the summer and fall of 1929 from demands of vegetation, ground evaporation, etc., no refill during the replenishing period and small amount of precipitation during the storage period following (1929–30). Copious rains, however, were had during March, April and May of 1930, with the result that ground storage was considerably replenished and ready to take the load during the coming growing period. After

TABLE 28.— MONTHLY VARIATIONS IN RAINFALL AT WEST HARTFORD. (1868–1933).

	Jan.	Feb.	Mar.	Apr.	May	June	
Normal run-off — inches	3.52	3.46	3.60	3.37	3.55	3.11	
Mean run-off per day — inches	0.1135	0.1235	0.1161	0.1122	0.1145	0.1036	
Departure from mean	−0.0066	+.0034	−.0040	−.0079	−.0056	−.0165	
Per cent. departure	−5.50	+2.84	−3.37	−6.59	−4.66	−16.49	
Per cent. annual "normal"	8.02	7.88	8.21	7.69	8.10	7.09	

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal run-off — inches	4.31	4.30	3.67	3.67	3.67	3.61	43.84
Mean run-off per day — inches	0.1391	0.1386	0.1223	0.1183	0.1223	0.1164	0.1201
Departure from mean	+.0190	+0.0185	+.0022	−.0018	+.0022	−.0037	.....
Per cent. departure	+15.83	+15.31	+1.77	−1.45	+1.77	−2.98	.....
Per cent. annual "normal"	9.84	9.83	8.37	8.37	8.37	8.23	.....

Mean per cent. departure $\Sigma D/12 = 6.55$ per cent. or the variation during the year with extreme limits above and below the mean of about 16 per cent.—per cent. D summed up regardless of sign.

Instead of February being the lowest rainfall period as indicated by the calendar analysis, it is actually the third highest period, if the actual number of days is taken into account.

D = Departure from mean.
Σ = Sum of.

this, the rainfall was sufficient for demands of vegetation and ample to fill ground storage, during the succeeding replenishing period (1930), storage period 1930–31 and growing period 1931, the greatest deficiency of rainfall not coming until after August. What precipitation then was received was nearly all credited to replenishing and ground storage, which practically refilled, regardless of the minimum low-rainfall period July 1931–June 1932. The effect of the low precipitation of 1931–32, however, was felt during the coming summer in run-off and ground storage conditions. Conditions of ground storage during these periods are shown in Figure 25.

Such variations in amount of precipitation and its dispersion through the year, lead to a consideration of monthly values, most important of the factors bearing on yield of watershed. Study of these divisions leads quickly to the conclusion that a much longer period is required to establish a "normal" for them, than that for annual records. For what they are worth at the present time, the data referring to monthly rainfall are presented in Table 27. It is also pertinent to remark here that "they ain't no sich animile" in the meteorological managerie as "general average conditions," there may and likely is a "mode" for both annual and monthly periods, but this mode will probably represent a comparatively small percentage of the total number of "samples."

Figure 26 made up from run-off records from several watersheds in the locality under study indicates the importance of differentiating between "mode" and "average." The average of the means of the 7 watershed yields is 1.70 cu. ft. per sec. (land surface) per sq. mile. The several records, however, differ among themselves from 1.55 to 1.98 cu. ft. per sec., a spread of 0.43 or about 28 per cent. of the lowest, and it is to be noted also that the periods of record differ considerably. Evidently, it is somewhat difficult to apply this "average" to an unknown watershed and to feel complete confidence in the result. It is helpful, however, to note that for about 30 per cent. of the total number of records the run-off has been stable at about 1.55 cu. ft. per sec. per sq. mile.

The mean values for the normal (calendar months) in the last line refer to U. S. normal period 1878–1927, inclusive (Table 22). From the data given in the table, it appears that the wettest month is July with 4.31 in. (normal) and the dryest month February with 3.46 in. (normal) a spread of 0.85 in. The difference between maximum and minimum of the same month in different years is considerable, as shown in the table, (West Hartford long record) the greatest range being found in October with a spread between 13.33 in. (1869) and 0.18 in. (1879) (13.15 in). (See Table 27, West Hartford Rainfall.) The average of all the monthly maxima and minima is 10.37 and 0.46 in. respectively, a spread of 9.91 in. This method of using calendar months, however, is not applicable to any study that requires accurate data on account of the varying length of the months, previously mentioned.

Periods of Drought.

Desmond FitzGerald seems to have been the first in this country to call attention to drought periods and their relation to water-supply requirements.[1] Following this report, came papers by F. P. Stearns[2] and FitzGerald[3] on ability of watersheds to furnish given quantities of water, and the classic paper on evaporation.[4] In his reports to the State Engineer, New York, on water storage on the Hudson and Genessee Rivers in 1896 and 1897, George W. Rafter opened up a wide path in these investigations and in 1903, produced his interesting and valuable monograph "Relation of Rainfall to Run-off."[5] In 1900[6] John R. Freeman greatly advanced knowledge of this character by his adaptation of the mass method proposed by Rippl[7] and mentioned by FitzGerald in his report on the Sudbury capacity referred to above. In 1908, Allen Hazen[8] made still further advance in the matter by his application of statistical methods, and by many other investigations that have added valuable information, applicable to the important problem of providing water supplies for communities. Following the work of these pioneers, many other students of hydrological problems have produced information of value and help, but most of it has been in the form of changes rung in on the original propositions with little result from original investigation.

As stated previously, it is well to keep in mind that a period of straight averages is not a suitable index of normality. There is considerable variation for mean or average in both annual rainfall and yield for the same watershed and from different watersheds among themselves with length of record and the particular period chosen. These differences (probabilities) for comparison can be simply worked out so far as practical use is concerned by procedures employed by Allen Hazen[9] in a paper on "Variations in Annual Rainfall" and by Thorndike Saville "Rainfall Data Interpreted by Laws of Probability."[10]

Instead of the "mean" or "average" the "mode" of the statistician approaches the requirement of a reasonable base most closely; *i.e.*, it is the most frequent amount in a given time. Mean is usually synonymous with average, and median is that quantity which, if all the records are put in order from least to greatest, is the mid figure of the array.

For the purpose of study of the kind here undertaken any reliable long record will answer for comparing periods by means of running averages. An example of these variations and their relationship to "normal" established from long period records for rainfall and run-off are portrayed in Figures 11, 17 and 21.

The tendency of yield generally to follow rainfall has been previously remarked in Figure 6 which also brings out the fact of less relative yield during periods of low rainfall and vice versa.

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[1] Report on the capacity of the Sudbury River and Lake Cochituate watersheds in time of Drought — 1887

[2] This Journal, 6 (1892), p. 102.

[3] *Trans. Am. Soc. Civ. Eng.*, 28, (1892).

[4] *Trans. Am. Soc. Civ. Eng.*, 15 (1886).

[5] *U. S. Geol. Surv.*, Wat. Sup. and Irr. Paper 80.

[6] Report upon New York's Water Supply.

[7] *Proc. Inst. Civ. Eng.*, 71, Pt. 1 (1882–3).

[8] *Trans. Am. Soc. Civ. Eng.*, 77 (1908).

[9] *Eng. News*, 75 (1916), p. 4.

[10] *Eng. News*. 76 (1917), p. 1208.

During the drought year, 1930, 83 per cent. of normal rainfall was received in the New England States January to September inclusive, and 88 per cent. during the same period in New York State. In the Southern and Middle West States, the rainfall was from 56 to 75 per cent. of normal for the given period, and during the period April-September, many of these states had as low as only 13 per cent. of normal. It is possible, of course, that the location of southern New England is such, as regards general atmospheric conditions, that it is extremely unlikely to be visited by such deficiency of rainfall as existed in the south and west during 1930. Nevertheless, it is only the part of prudence at least to concede that conditions much more serious as regards water supply than have hitherto been experienced may occur in this locality in the future. When and how meteorological conditions occur is at present mostly speculative, and with present knowledge, it is impossible to forecast either the time of the occurrence or the limits of their intensity.

For the New England States, in January–October, 1930, the following per cent. of normal precipitation was received:*

Month.	Per cent.	Month.	Per cent.
January	79	June	102
February	64	July	102
March	127	August	66
April	50	September	48
May	107	October	83

For the whole period, the average was 83 per cent. and for March to August, 92 per cent. The period rainfall, March to August, was, for New York, 90 per cent., Maryland and Delaware, 55 per cent., and Pennsylvania, 71 per cent. A little shifting of the area of high pressure over the Atlantic Ocean during the period would have brought Maryland's conditions to southern New England. Had the low pressure areas in 1930 been located somewhat differently than they were with respect to the storm track, the southerly edge of which kept some rain for New England and New York, conditions infinitely worse than happened would have been experienced.

Per cent. of rainfall to the normal is, however, not the index of that condition which brings about what is commonly called "drought" in its relation to water supply. In every locality, there must be some irreducible minimum of rainfall, below which vegetation cannot flourish or even live, and as this is approached, water available for water supply becomes less and less available. What this limit is, we, here in New England, have happily never experienced. It is evident, therefore, that, even with normal annual rainfall, the time of the year in which a period of scant rainfall occurs and the purpose for which rain is necessary has much to do with the results of the so-called "drought." Scant rainfall during what Rafter†

Monthly Wea. Bu., Sept. 1930, p. 352. †*U. S. Geol. Sur.*, Wat. Sup. and Irr. Paper 80.

designated as the "growing period" (June to August) may be serious as regards vegetation, but possibly not so troublesome for water supply with rainfall in the "storage period" (December to May) normal or above. On the other hand, plant life may not suffer excessively if normal conditions of rainfall prevail during the growing season, although water supply may be considerably depleted if there was a sufficient deficiency of rain during the preceding "storage period" to cause a condition of low ground water and lowering of the moisture content of the soil.

A general warning to draw from these statements is that if ground water is not at or near normal by May 1, there is danger of low water in water-supply reservoirs during the coming summer, regardless of the rainfall during that time; that is, the natural demands of vegetation and evaporation during the summer or growing season are sufficient in amount to need practically all of the rainfall under normal conditions, leaving to stream flow and water-supply development only the amount of water stored during the previous period, either in the ground or in reservoirs.

These statements lead again to a discussion of fluctuation in monthly rainfall, which has been touched on to some extent previously. Due to its geographical location, southern New England is favored with a normal rainfall very evenly distributed throughout the year. While the matter of difference in length of the several months of the year presents difficulties in direct comparisons, recognized by meteorologists and overcome to some extent by a method devised by Angot in France and followed by several British authorities,[1] in the present discussion, the calendar months have been used as being more familiar divisions.

Monthly normals at Weather Bureau stations are obtained from the records of the several months in the U. S. Normal period 1878–1927, although as is pointed out by Mills and Salter,[2] the amount of rainfall for these periods fluctuates around these normals much more than in the case of annual amounts. A considerably longer period, therefore, possibly one hundred years, is necessary in order to fix monthly average values within small limits.

In September, 1914,[3] a report of a Committee of this Association was received on "Yield of Drainage Areas." The origin of this report is found in the years of exceedingly low rainfall and yield of watersheds in New England, 1909–12. In reviewing conditions of this drought, after the lapse of years, it is possible now to make some general observations and comparisons which could not have been done at the time of occurrence on account of proximity to the period and lack of necessary data. A period of twenty years has now passed with records completed and consolidated. The twenty-year addition to all of the records then available to the Committee, gives a stability to records that justifies considerable confidence in deductions which are based thereon.

[1] C. B. Wallis, *Quart. Jour. Roy. Met. Soc.* 40 (1914), p. 311.
[2] *Quart. Jour. Roy. Met. Soc.*, Jan. 1915, p. 1. [3] This JOURNAL, 28 (1914), p. 397.

The Wachusett (Mass.) record covers 36 years (1897–1932); that of Sudbury (Mass.), 58 years (1875–1932); and of the Croton (N. Y.), 65 years (1868–1932), all giving both rainfall and yield. On the Wachusett watershed, with its shorter record, the extreme low-flow yield occurred during the 6-year period, 1908–1913. The average yield (calendar years) for *land surface only*; *i.e.*, corrected for water surface, was 1.40 cu. ft. per sec. per sq. mile, an amount 80.4 per cent. of the 36-year average. Since this period, as well as prior to it, have occurred other periods during which rainfall and run-off conditions have been even more extreme in some respects than those of 1908–13, which were the cause of the Committee's report. Quoting from the report* of the Metropolitan District Commission (Mass.) for the year 1930:

The total precipitation during 1930 on the Wachusett watershed was 34.97 in., is 9.88 in. below the average for 34 years (77.5 per cent. of average) and the lowest recorded on that watershed during that period; on the Sudbury watershed, 34.40 in. is 9.90 in. below the average for 56 years (73.8 per cent. of average) and only 1.62 in. above the minimum of that period of 32.78 in. in 1883; and on the Cochituate watershed, 33.69 in. is 11.09 in. below the average for 68 years (75.4 per cent. of average) during which period the minimum precipitation was 31.20 in. in 1883, while in 1908, there was only 33.03 in.

The average daily yield per square mile for all of the watersheds was the lowest of record, 566 000 (0.876 c.f.s.) from the Wachusett, which is 53 per cent. of the average for 34 years; 339 000 gal. (0.617 c.f.s.) from the Sudbury, 41 per cent. of the average for 56 years; and 428 000 gal. (0.662 c.f.s.) from the Cochituate, which is 46 per cent. of the average for 68 years.

During 1930, on the Croton watershed (New York City Supply), conditions were not quite so extreme as on the Boston supply area. Rainfall for the year was 39.44 in., which was 8.41 in. below the 63-year average (82.5 per cent. below average). The previous minimum year, 1917, had a rainfall of 36.28 in.; *i.e.*, 3.16 in. below that of 1930 and only 75.8 per cent. of the average. On the Sudbury, the lowest rainfall of record was 32.78 in. in 1883, which is 73.9 per cent. of the average for that period. The rainfall for that year on the Croton was 43.05 in. The average for the years (58) of rainfall on the Sudbury is 44.36 in., on the Croton (63 years) 47.85 in. Attention is called to these relations, as the two stations are located approximately similar distances from the sea but with entirely different exposures to prevailing wind direction.

Ann. Rep. Met. Dist. Comm., Nov. 1930, p. 15.

Conclusion.

In closing this paper, which, as previously stated, was intended to be a presentation of facts and records, it seems desirable to call attention again to the necessity of careful consideration of the length of record before drawing conclusion therefrom. As a help in this matter, Figure 11, for rainfall, was presented. Figure 21 for run-off conditions on the Sudbury and Croton watersheds is also given as an indication of the length of record required in this respect.

From the figures here given, Figure 11, it is quite clear that the "Nepaug" record of twenty years is not sufficiently representative of rainfall conditions on that area to warrant estimates within a reasonable accuracy of less than about 5 per cent., and that a run-off record of from 35 to 40 years is necessary to establish confidence in results within that same limit. The yield of the Croton watershed in 1930 was at a rate of 660 000 gal. (1.02 cu. ft. per sec.) per day per sq. mile, 61 per cent. of normal. The minimum yield year on this watershed was that of 1880, with 554 000 gal. (0.857 cu. ft. per sec.) per sq. mile, or 51.3 per cent. of normal. Rainfall and yield in order of minima during the 20-year "Nepaug" record, are given in Tables 6 and 7. For frequency of mean annual run-off for the periods of record on small southern New England watersheds, Figure 26 is presented. From this, it is to be noted that for about 30 per cent. of the period of record, the most frequent (mode) run-off figure was 1.58 cu. ft. per sec. per sq. mile, an amount about 7 per cent. less than the weighted mean.

So far as water supply is concerned, periods of low rainfall of five years or less are of most immediate importance. The longer periods, as the 20-year averages, are of most use in placing a shorter record in its relative position in the historical sequence. For example, in the West Hartford record of 65 years, Figure 12, it is evident that the 5-year period ending 1883 is much the lowest of the whole series. The 20-year record from this station, placed in position on the nearby Amherst record, Figure 14, with its 30-year longer history, indicates the probability that during the preceding 100 years, the average 1913–1932 rainfall in this vicinity is about the lowest period of this length yet experienced and that the Nepaug rainfall record for the same period only may be considered as an exceedingly low period in spite of its several years of high rainfall. Also, that while the 5-year period 1908–12 was one of excessively low rainfall, the 20-year average was relatively high due to extensive rainfall in preceding years. It is of interest to note that while the 20-year averages for both stations since 1895 are in close agreement, previous to that time, there is some divergence. Regarding the 5-year periods, however, the peaks and valleys are as nearly coincident as could reasonably be expected. Observing the 5-year low averages for the period prior to 1850 and the number of these periods reaching back to the beginning of the record, it seems reasonable to conclude

that this period of history may well have been subjected to periods of drought far exceeding any experienced since.

In studying the long-term records of rainfall from which Figure 15 and Table 23 resulted, decadal averages in order of magnitude of rainfall beginning with the least, are as follows:

Order.	Period.	Per cent. of Base.*
1	1760–1769	83.4
2	1790–1799	88.6
3	1910–1919	91.9
4	1770–1779	95.0
5	1830–1839	95.7
6	1840–1849	96.4

It will be observed that these decades begin with "zero" years, and that all but one (1910–1919) were prior to West Hartford rainfall history, which began in 1868. It seems probable, therefore, that the amounts of rain received in that locality for the preceding 118 years at least were as little, and probably less, than the amounts given in the record. If the 10-year periods chosen for averaging had ended with 1932 instead of 1929, the per cent. of base received would have been 93.7 per cent., ranking this period with the others as Number 4 or some 2.4 per cent. more than that of 1910–1919.

Regarding the reliability of the older rainfall records: There is not much doubt that methods of observation and record have been vastly improved in the past 50 or 60 years, and for accuracy in regard to the amount of precipitation from individual storms or indeed annual records of both drought and flood years, present-day technic results in more precise measurements. Nevertheless, in spite of many glaring inconsistencies, we are extremely fortunate to have these older records, and they are all that we do have from which to judge of general rainfall condition of the past, *i.e.*, periods of drought and flood and their relative value in connection with present-day records for water-supply purposes. It may be that in spite of our care and so-called accuracy at the present time, those who are using our records 50 or 100 years hence may find them as crudely obtained as those of that earlier period which we are prone now to criticize. The principal use of old records is to indicate what the future may expect, and, therefore, general tendencies if they are founded on sufficient fact to be considered reliable are all that one should require.

As to unit records, either of individual storms or to a lesser degree separate years, these are sporadic occurrences in water-supply history, and there is no reason to believe that their happenings are more excessive or of lesser amount in the past than in the period of so-called modern precision. That is to say any good record of sufficient length to be representative has

*Base used by Marvin.

probably included several excessive storms, but it is exceedingly doubtful if any record ordinarily extant has included such drought periods as are liable to come at any time.

Generally speaking for water-supply purposes, we wish to know, if in the past there probably were periods of three, four or five years consecutively when the rainfall was appreciably lower than that of the 50 or 60-year modern records. This information does not require exact precision of individual raingage records, as is necessary for sewerage or spillway design. If two, three or four stations indicate a period of extremely low rainfall, that would be sufficient for the purpose of comparison with present more authentic information.

The position of the period since 1904, as shown in Figure 15, is plainly on the downward path of rainfall as is also indicated by the five-year curve of departure shown in Figure 12. Prior to 1904 the records show gradually increasing rainfall since about 1849 (Fig. 15).

As stated at the outset of this paper the original reason for undertaking this study was the difference in yield from the Nepaug watershed between actual experience during the past 20 years and the computed estimate of yield when the works were started in 1912–13. It seems probable now that one cause of this difference was failure to take into account all of the factors, although the method used was the standard of the time of using the only guide then available, *i.e.*, the long-time records of rainfall and yield from the Croton River (N. Y.) and Sudbury River (Mass.) and the methods deduced from them by masters of hydrology in this country. Not until after the middle of the past decade was scientific thought focused strongly upon meteorological happenings and their correlation to hydraulic science.

In 1913* the "safe" yield of the Nepaug Reservoir and its 31 sq. miles was estimated as 26 m.g.d. per sq. mile on the basis of Sudbury data (1875–1912), and about 31 m.g.d. per sq. mile on basis of Wachusett data (1897–1912). During the recent drought period, 1929–32, measurements of stream flow and rainfall show that 25 m.g.d. per sq. mile is the limit of this watershed with its storage of 9 000 m.g. per sq. mile. The yield records of the Croton and Sudbury watersheds at that time were obtained principally during the long upward swing of the rainfall cycle (Figs. 15 and 18), whereas present experience on the Nepaug development has come on the downward path 1912–1932. The importance of this position in the long-term record of the hydrological and meteorological data used has been clearly presented by A. Streiff† and some earlier reference has been made to it by R. E. Horton.‡ Undoubtedly this matter has not in the past received the attention which its apparent importance merits in forecasting water yield and possibly removing its study somewhat further from the fortuitous to the scientific. A little consideration of this matter of meteorological and hydrological occurrence, even without complete acceptance of the more

*59th *Annual Report.* Bd. Water Comm., Hartford, p. 31 †*Civil Engineering*, Nov. 1932, p. 690.
‡*U. S. Geol. Survey*, Wat. Sup. and Irr. Paper 30.

advanced thought of correlations with solar phenomena may result in more reliable solution of problems which are of importance to the safety and welfare of many people. The experience of the past is the most reliable guide for the future, but in order to use that experience safely, it is necessary to use *all* of the facts which the past has provided.

In any study of rainfall over long periods two outstanding facts are evident: (1) That there are periodic waves in the record during which the general average is decreasing to a minimum and thereafter increasing to a maximum with evident tendency to again show decrease as the future unrolls. This tendency is shown plainly in Figure 18.

(2) Accompanying these long-period swings are other oscillations of more or less amplitude, corresponding somewhat to the so-called "seiches" in large lakes and the oceans, where for several years there will be either excess or deficiency in rainfall, although the general tendency has a distinct upward or downward trend. These latter fluctuations are those most significant in water-supply work, but position on the long-time record of a station is a most important factor in effectively determining the safe probable yield of a watershed.

As in the case of other natural resources of this country, there has been in the past such an abundance of water that it has been unnecessary to consider too closely what may be the actual dependable yield of a watershed. With increase and concentration of population and greater demand for more abundant water supply, it is becoming evident that more careful analysis must be made of the factors on which estimate of ultimate capacity depends both for available amount and development of economy.

The principal purpose of this study was to ascertain as nearly as possible the ultimate safe capacity of the water-supply sources of the Hartford Metropolitan District. After satisfying this objective, the only other thought has been to provide a store chest, as it were, for some of the tools which have been developed as the work progressed, so that if desired they might be available to others making similar search in hydrological fields and byways.

PROCEEDINGS.

NOVEMBER MEETING.

HOTEL KENMORE, BOSTON, MASS.

Wednesday, November 8, 1933.

President E. Sherman Chase in the Chair.

Secretary GIFFORD. At the executive committee meeting this morning the following were elected members: Lewis C. Sanford, Superintendent, Rockport, Mass.; Ralph M. Palmer, Chemical Engineer, New York, N. Y.; Thomas B. Ray, Engineer, Oxford Water Co., Millbury, Mass.; Joseph C. Knox, Assistant Engineer, Massachusetts Department of Public Works, Boston, Mass.

Since the last meeting the following members have passed away:

J. Waldo Smith, (New York City), October 14, 1933.

Albert L. Sawyer, (Haverhill), September 25, 1933.

George A. Adams, (Needham), September 5, 1933.

L. Henry Kunhardt, (Boston), September 30, 1933.

Charles R. Preston, (Lowell), September 26, 1933.

Frederic V. Pitney, (Newark, N. J.), October 23, 1933.

Morris R. Sherrerd, (Newark, N. J.), October 19, 1933.

THE PRESIDENT. I will ask the members to arise for a moment in silent tribute to the memory of those of our members who have passed away.

(The members rise and stand in silence.)

I have to announce that at the executive committee meeting this morning it was voted unanimously to appoint Mr. Leland G. Carlton, Water Registrar of Springfield, Massachusetts, to fill the unexpired term of our late treasurer, Mr. Sawyer.

Another matter which I think should be brought to the attention of the association today is the fact that two of our eminent and distinguished members, both of whom are honorary members, are retiring from active public service this year. I refer to the retirement of Mr. Harry W. Clark of the Massachusetts Department of Public Health, and to the retirement of Sir Alexander C. Houston, Director of Water Examinations of the City of London, Metropolitan Water Board, England.

WARREN J. SCOTT.* Mr. President, I would like to present this resolution to the Association, if I may:

That the President of the New England Water Works Association be authorized to extend the high appreciation of the Association for the distinguished services rendered to the water-works profession by its Honorary

*Connecticut State Department of Health, Hartford, Conn.

Members, Harry W. Clark, Massachusetts Department of Public Health, and Sir Alexander Houston, Metropolitan Water Board of London, England, whose retirements from public life occur this year.

(The resolution is duly seconded and unanimously carried.)

A paper "Recent Additions to the Cambridge, Mass., Water Supply," was read by Howard M. Turner, Member of the Cambridge Water Board and Consulting Engineer, Boston, Mass. Messrs. Henry F. Beal, Lewis M. Hastings, Timothy W. Good, Percy A. Shaw, Samuel W. Ellsworth, and G. K. Saurwein took part in the discussion.

A paper "Corrosion of Brass in Water Subjected to pH Correction," was read by Edward W. Moore, Instructor in Sanitary Chemistry, Harvard University, Cambridge, Mass. Messrs. F. G. Smith, E. L. Bean, Peter P. Kosting, David A. Heffernan, Gordon M. Fair, E. Sherman Chase, and Harry W. Clark, participated in the discussion.

(*Adjourned.*)

Federal Emergency Public Works Administration.

REMARKS BY L. A. HOFFMAN.*

[September 22, 1933.]

We are now engaged in a war not less serious, despite the absence of the uniform, than the World War in 1917. A struggle involving the question whether or not we are going to continue our present form of economic and social structure. As we look at the countries of the world we recognize that there are few indeed which have maintained their political and economic status as it was but ten years ago. We must be foresighted enough to see the march of very definite social trends and to control those trends by anticipating them rather than permitting an extreme swing of the pendulum. This is a war being waged on several fronts, one of which is the Federal Emergency Public Works program.

The National Industrial Recovery Act sets up two correlated functions. The first is the establishment of codes of fair competition. That portion of the act is under the direction of General Johnson. The second is the Public Works program, whereby up to $3 300 000 000 are to be poured into this country's economic life stream through public works projects and is under the direction of Secretary Ickes. The first of these functions will tend to increase prices; the second will increase purchasing power and will tend to offset the lag in earnings which ordinarily accompanies increase of prices. This reduction of the lag by the introduction of money through channels of legitimate work, I think, was a mighty farsighted bit of legislation; one that is all the more to be commended in the light of the rapidity with which it was formulated.

In the execution of this program, we shall require the warm coöperation of technical and civic organizations. The New England Water Works Association is one with which we shall have the pleasure of coöperating to the fullest extent. Among corollary organizations, and possibly identified in the membership of this Association, are the state departments of health, the state water commissions, as well as municipal public works organizations. Of course we want and shall continue to coöperate more and more warmly with the professional organizations as well.

We have in this program a splendid opportunity, particularly those in such public works activities as Water Works men, to bring into effect long-range planning, long-range work of the kind that has been undertaken by men such as Mr. Saville of Hartford and others engaged in similar work. Consider, for instance what Mr. Senior, of the Bridgeport Hydraulic Company, has been doing by way of future planning for the Bridgeport district; the Easton Dam project and the reserve watershed, which the company,

*State Engineer for Connecticut and Rhode Island, Federal Emergency Public Works Administration, Bridgeport, Conn.

under his direction, has been carefully developing over a long period of years. Similar work has been conducted by our good friend Mr. Winsor, who you will recall was largely responsible for the Providence water-works project, and who is now identified with the Metropolitan District Water Supply Commission of Boston.

That is the sort of thing to which we can well afford to devote our attention; work which is not just designed as a check to unemployment, with no other goal, but which will do that as well as a good to the community, a good to the states and to New England. You are interested not alone in Rhode Island, Connecticut or Massachusetts, or the individual cities or towns, but in the integrated effects of this drive on the depression.

We must do two things in this public works program: first, take up the slack in employment; and second, increase the buying power of the public at large, not alone in that community in which the slack has been taken up, but in general, by the introduction of funds through legitimate channels. It is an essential part of the purpose of the whole act.

I dare say that there are in the Association a number of men who have in their minds projects which may come before the boards of the various states in New England; projects concerning which they are anxious to get information in order to present them adequately to the State Board and the State Engineer without incurring an obligation for engineering services, drafting and field service, beyond those necessary for their intelligent review. In other words, if the project is likely to be turned down, these men do not want to spend a large sum to bring it to the stage of being turned down. May I point out the extent to which information must be complete and the necessity for such information.

The Advisory Board and the State Engineer review these projects with an eye to their feasibility, their costs and their desirability from the standpoint of long-range planning in the community. When the projects leave the Board's and the State Engineer's hands, they go to Washington. Here, they are reviewed by a group impartial in its attitude, who have no local interest, no local picture or background, or a personal realization of what the need may be. It is therefore imperative that the presentation of the conditions and the picture through the submission of the application by word description and the exhibits that are included shall give the information necessary to pass upon the project without the necessity of passing it back and forth between the state administration and Washington in order to ascertain the essential information.

While we have been, in some instances, accused of a certain amount of red tape, insofar as it has been possible, that has been reduced to an extent where it does what I have just tried to bring out,— develop the picture of the local situation, so that it can be intelligently read at Washington and passed upon. It seems that those loudest in their cry of "red tape" are those least willing to exert a guided effort to secure Federal aid and those who expect the State Engineer's office to work up their application.

It is not necessary that plans be submitted in finished form; in the form which is necessary in submitting them for bidding. Plans can be submitted which give a comprehensive picture and are in enough detail to permit the engineer to pass upon the feasibility of the project; in enough detail that the estimates may be reasonably checked so that they indicate, for instance, in the case of water-works projects, whether the terrain through which a water line will pass is likely to include a great deal of ledge or soft gravel digging, and other essential information of that character.

The information must also clearly state the fact that the community is legally empowered to enter upon the program, that it is not prohibited by charter or special legislative act from undertaking such a project and that, from the financial standpoint, its bill of health is such as to warrant the people taking on the additional burden and obligation, long-range though it may be, without entailing disadvantages which more than offset the advantages the community will receive now by virtue of unemployment relief. Those are matters that the individual localities can best measure.

May I say here that it is indeed unfortunate that those communities with the highest unemployment figures are likewise the communities in the poorest financial status. Perhaps cause and effect have been recognized in the framing of this act as in that of supplementary enabling acts on the part of a number of the states. Unfortunately some of the state acts have unwittingly incorporated conditions which have tended to slow down rather than speed up the program; they are trying to correct those now. In the state of Connecticut we have an act empowering the Emergency Relief Commission (Brainard Commission) under certain conditions to permit a community to exceed its limit of bonded indebtedness. This is Chapter 276 of the Public Acts of 1933. In Rhode Island, the state set up an Emergency Public Works Commission headed by the Governor, empowered not only to expand a community's borrowing power but to review all projects before submission to the Federal Advisory Board.

The Federal Government in entering into this work is not giving away money. It is not to be thought that the so-called grant is an outright gift. The grant itself is intended as an inducement to get work under way at this time and offset the increased cost of materials and labor resulting from the adoption of codes of fair practice and the wage rates which are incorporated in the contracts between the Federal Government and the applicant and likewise between the applicant and the contractors as a condition on which Federal aid is given. It is intended that through the starting of these public works projects the heavy direct relief burden upon the municipalities will be relieved by employment on constructive work.

Some of you may have asked, "What is the use of a community going into this program if it has to pay rates which will very near balance the advantage of the grant?" Probably the easiest way to take care of a number of relief cases is to "dole" out the cash. This method avoids the need of layout, a work plan and creating real value. Worst of all, it finally breaks down the recipient's morale. In too many instances, where construction

programs have been undertaken, the rates for such work have been miserably insufficient. A primary purpose of this most humanitarian act, the N. I. R. A., is to permit men to earn reasonable wages and thereby create increased buying and consumptive capacity. This program is for broadening the interests of the individual city or town; it calls for unselfish, patriotic support.

As to the "force account" problem: Under certain circumstances, where experience over a period of years has indicated that the city has the wholesome, wholehearted respect of its leading, high minded citizenry, force account work may be granted. By "force account" is meant, the carrying on of public works under the personnel and directionship of the municipal organization. There will be communities who, under this program, will not be permitted to conduct work on "force account"; not because the community may not be perfectly sound in its administration, but because the very nature of the project that has been applied for will not permit the kind of control that will make it possible to see that the handling of public funds is above the suspicion of graft or unwise expenditure.

There seems to be need for clarifying the terms "loan" and "grant." Just what is meant by "loan" and "grant"? A project costing one million dollars may include services for engineering amounting to say 5 per cent.; or $50 000. Land may have to be acquired; rights of way and easements secured which together with contractors' profits, interest and use of equipment, amount to $150 000. Such items which do not fall under the caption of material and labor must be deducted from the project as a whole, before applying the 30 per cent. factor which determines the amount of the grant. Included as permissible under the caption of material is such an item as the prorated depreciation of large contract equipment used on the job. That is admissible on the theory that the replacement of that proportion of the equipment used on the job gives work.*

For the project we have under consideration, the deductible items come to $200 000, leaving of the $1 000 000 project, $800 000 representing the sum total of material and direct labor; $240 000 represent 30 per cent. of $800 000 and are the amount of the grant if $800 000 were actually spent on material and labor on this job. In the event that the community was in a position to finance the $760 000, the difference between the $240 000 and the $1 000 000, it would then request only the grant.

Applications for work ready to start and asking for grant only are particularly solicited for two reasons: First, the time required to draw contracts is shorter than when loans are asked; second, the amount of money tied up in the project — $240 000 instead of $1 000 000 in our case — allows this $3 300 000 000 fund to be spread over a greater number of projects, thereby providing work to a greater extent. This does not mean that the Federal authorities look with disfavor on the loan application.

*A change in ruling has since been issued designating all charges for equipment, its use or depreciation, as not admissible under material and labor.

Suppose the applicant is not in a position to float the obligations to advantage, but desires to have the Federal authorities do the financing as well as making a grant. He may then apply for the loan of the entire amount, the $1 000 000, or for a loan of the $760 000, the balance between the $1 000 000 and the grant. Let me indicate two ways of handling the loan. If the whole $1 000 000 is taken as the loan, the amount of the grant may be applied as a credit account to meet interest and amortization over the first four years or so, depending on the life of the bond. In this way the community does not make any outlay for the amortization of and the interest on that obligation until the grant amount has been used up. Another plan is to be obligated for the amount of the difference between the grant and the project — in this case $760 000 — when the interest and amortization start, of course, immediately with the incurring of the obligation. The amortization period will reflect the nature of the project, complying with the law where such legislation exists and preferably not to exceed a maximum of 30 years.

The Federal Government in buying loans does so by bidding in the open market. Through the Federal Reserve Bank it enters a bid of 4 per cent. par. If the community can sell those securities in the open market on a basis of 3⅞ per cent., it is, of course, to the interest of the community to secure its money in the open market. It may even be to the interest of the community to pay 4¼ per cent. in order to get the work started immediately.

A question frequently asked is: "Does the Federal law, the NIRA, provide for direct negotiation with a municipality already up to its limit of indebtedness or prevented by statute from borrowing?" It does so provide. A city or town which should incur an indebtedness outside its legal limit would certainly find its financial standing impaired since the state could not recognize such an obligation. Thus from a practical standpoint, unless an obligation of a municipality is recognized as legal within that state, the hope of Federal financing of the work beyond the grant is very slim.

After a project has been accepted by the Administration and the funds allotted, the work has to be started. Contracts must be drawn safeguarding to the community that it is going to get what it bargained for, and that the conditions under which Federal funds are made available will obtain in the execution of the work. That requires a Federal policing service, an inspection service, which will be in addition to the regular safeguards set up by the engineer or the town itself.

There must be incorporated in the contract between the applicant and the contractor provisions for fair play with respect to wages, conditions of labor and hours of employment on the one hand and their reflection in costs of the project on the other. Public Works Administration projects will in general be conducted on a 30 hour per week basis with minimum wage rates in New England of 50c per hour for unskilled and $1.20 per hour for skilled labor. In order to furnish a fair basis for bidding by con-

tractors and give assurance that bids are comparable and protect labor from unscrupulous employers, some schedule will have to be worked up for the intermediate groups of labor. It is intended that in the P.W.A. schedule an intermediate rate will be reasonably proportionate to the rate paid that classification in the prevailing scale. The contracts also provide that prevailing rates will apply when they are in excess of the P.W.A. rates.

Some of us are concerned about what we consider high rates. But let us look at them not in the light of rates, but in the light of what there is in the pay envelope for a week of 30 hours. It amounts to $15 for common labor and $36 for skilled labor with intermediate amounts in between. These are certainly not over-filled envelopes.

As a Federal state engineer of New England I most sincerely solicit the coöperation of the members of this Association. I want you to feel free to send inquiries for information that will help you to put these applications into such form as will expedite their approval and development in the field. We must have enough information to be assured that the project is feasible, that its costs are soundly developed, that it meets a need in the community, that it is desired, that there are no particularly justified elements against it, that the community has the legal right to obligate itself for that particular purpose, and that such financial obligation as is entailed is sound.

To you, the members of the New England Water Works Association, is open the opportunity through your close association with our municipalities to promote intelligently projects of lasting benefit. Projects that are put under way NOW, if necessary with the aid of Federal funds, will be your contribution in getting men back to work and increasing the purchsing power of our people.

REMARKS BY E. SHERMAN CHASE.*

There is not very much to report on behalf of the New England Recovery Committee for Water Works Construction of this Association. This committee was formed as a result of the action of the Executive Committee in June, which in turn was stimulated by the action of the American Water Works Association at the Chicago Convention in the formation of a national committee to stimulate water works construction throughout the country under the National Industrial Recovery Act, Title II.

In order to avoid an overlapping in New England of the activities of the two associations, your Association volunteered to coöperate with the American Water Works Association's committee, and as a sort of a sub-

*Chairman New England Recovery Committee for Water Works Construction.

committee of this national committee we have been functioning according to our lights.

One of the first acts of the committee was to circularize the membership calling attention to the general provisions of the Recovery Act, Title II, and urging municipalities throughout New England which had worthy water-supply projects to take the preliminary steps for the securing of the benefits of the Act.

Due to the time required at Washington for the perfection of the Federal organization to handle the vast program of public works throughout the country your committee was unable to furnish you with very much authentic information at first; but as fast as information was obtained it was sent out to the membership. You have already received copies of the Act, and copies of circulars 1 and 2.

In addition to the work of informing the membership of the provisions of the Act and the various steps required for the securing of its benefits, we have been attempting to compile such data as we could with respect to prospective water-supply betterments throughout New England which could be benefited by the Federal action.

Furthermore, as chairman of your committee, I spoke at the Maine Water Utilities Association meeting last August, explaining the provisions of the Act and the measures necessary to obtain funds. As a result of that talk, the Maine Utilities Association formed another committee to coöperate with the New England committee. Furthermore, the individual members of the committee have contributed personal work, in so far as they were able, in getting into touch with municipal public officials, where there was some opportunity of fostering public works construction, particularly in the water-works field. As a matter of fact, it is probably true that the most effective work has been done through personal contact.

One other matter about which the committee was considerably concerned was the rumor that public works, to be benefited by the Act, must be executed by regular contracts rather than by force account. This was particularly disturbing in view of the fact that many water departments are adequately organized to carry out their own construction work by force account. Even some of the Federal state engineers were under the impression that there was no alternative but to have public works programs carried out by formal contract and not by force account. After telegraphing to the Administrator in Washington we received a ruling from Colonel Waite, as follows:

> In reply to your telegram of August 25 addressed to Hon. Harold L. Ickes, you are informed that our regulations contemplate that bids will be received and contracts will be let for all works financed from funds appropriated by the Administrator of Public Works under authority of the National Industrial Recovery Act, and that deviation from this practice must have the approval of the Administrator.
>
> In the case of the State of Massachusetts, or other states in New England desiring to execute construction by force account, the request for authority to adopt that method should be made to the Administrator through the State Advisory Board.

In one instance where the request for such permission was made in the application the administration sent a special investigator to that city to go over the project in order to determine if force account was a proper method to adopt in that particular instance. The permission to carry out the work by force account was granted rather promptly.

The activities of the committee were not very extensive, but as a matter of fact there was not much we could do until the administration in Washington promulgated its rulings and regulations and until rulings had been obtained on various matters about which there were doubts.

In Massachusetts there is one extra hurdle to overcome with respect to receiving approval of projects: that is, any project in Massachusetts which is expected to be financed under Title II of the Recovery Act must secure the approval of the Governor, who acts through the State Emergency Finance Board. But the State Emergency Finance Board of Massachusetts has functioned in such a way as to reduce the lost motion to the minimum, because this board has coöperated fully with the Federal set-up in Massachusetts, and *vice versa*. Apparently the Massachusetts Board examines the applications particularly with reference to the financial ability of the municipality to assume the burden of the new works, and also with respect to the social usefulness of the project contemplated, leaving to the Federal Administration inquiry into the engineering features of the project.

One of the principal reasons for delays in securing the approval of projects, in addition to the more or less inevitable red tape and the safeguards which must be thrown around the Federal expenditure of $3 300 000 000, is the failure of the local officials to take seriously Circular No. 2. Circular No. 2 does go into many details, and asks many pertinent, and to some of us perhaps impertinent, questions; but Circular No. 2 is there, and the way to overcome that hurdle is to jump over it and not try to run around it, because if you do try to run around it there is going to be somebody who will turn you back and make you jump over anyway. The thing to do is to accept the hurdle and take the jump. In other words, fill out your application data just as completely, as well and concisely, as you can, so that the examination of the applications can be made quickly and without having the material returned to you for further information. The better shape your application is in, the sooner you will get your assistance. That particular point cannot be emphasized too strongly.